2011 Research in Engineering Education Symposium

Program and Proceedings

1) October 4-7, 2011

Madrid, Spain

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We gratefully acknowledge the support of the following sponsors
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- Investigating and addressing student difficulties in introductory electrical engineering
- Analytical tools in engineering education research: The “learning a complex concept” model, threshold concepts and key concepts in understanding and designing for student learning
- Methodology for automated generation of multiple choice questions in self-assessment

Topic: Teaching and Learning 1 – Chair: Jennifer Turn
- A qualitative inquiry into first year engineering student success
- Sharing the past, sharing the future, and sharing oneself in portfolio studios
- Engineering Student’s Conceptions of Model Uses in Design

Topic: Tools 1 – Chair: Barbara M. Olds
- Instrumental development: Engineering-specific Epistemological/Ontological beliefs
- Virtual Instruments in dimensional metrology
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Topic: Learning strategies 1 – Chair: Bill Williams
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Topic: EER – Chair: Llewellyn Mann
- Strategic pathways to engineering education research: a top-down case study
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Welcome message

Research in Engineering Education Symposium 2011

It is my pleasure to warmly welcome you to the 2011 Research in Engineering Education Symposium being held in Madrid, Spain, October 4-7, 2011. The main theme of the conference is Engineering Education Research and the purpose of REES is to build a global community of researchers in engineering education. As in previous years, we are seeking contributions that represent high-quality research activity across a diverse range of research traditions and will contribute to engaged conversations during the conference. Participants should come ready to share, discuss, debate, encourage and leave with at least one new research partner.

The conference has been organized by an international Planning Committee of colleagues in the field of engineering education research, supported and hosted by the Universidad Politécnica de Madrid (UPM). Sponsors include the Vicerrectorado de Ordenación Académica y Planificación Estratégica UPM (gold sponsor), EUIT de Telecomunicación UPM (bronze sponsor), EU de Informática UPM (bronze sponsor), ETS de Ingenieros Aeronáuticos UPM (bronze sponsor), EUIT de Aeronáutica UPM (bronze sponsor), Madrid Convention Bureau (bronze sponsor) and the Journal of Engineering Education (bronze sponsor).

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luismanuelcerdasuarez@gmail.com
# Conference Planning

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<th>Time</th>
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<tbody>
<tr>
<td>18:00-20:30</td>
<td>Welcome Reception</td>
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<td>Hotel Best Western Santo Domingo</td>
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<td>Socratic Session</td>
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<td>Coffee break</td>
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<td>11:30-13:00</td>
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<td>Threshold Issues</td>
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<td>Teaching &amp; Learning 1</td>
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<td>Tools 1</td>
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<td>Learning Strategies 1</td>
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<td>13:00-14:30</td>
<td>Lunch</td>
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<td>14:30-16:30</td>
<td>Second Session</td>
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<td>EER</td>
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<td>PBL</td>
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<td>Technology in Learning</td>
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<td>16:30-16:45</td>
<td>Coffee break</td>
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## Thursday, 6th October

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<tr>
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<tr>
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<td>Third Session</td>
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<td><strong>Technology in Learning</strong></td>
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<td><strong>Teaching Practice</strong></td>
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<td>18:45-21:00</td>
<td>Guided Tour</td>
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<td>“Madrid de los Austrias”</td>
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<td>Organised by: Madrid Convention bureau</td>
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<td>21:00-22:30</td>
<td>Dinner in the restaurant</td>
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<td>Bus travel</td>
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<td>“Bodegas Tagonius”</td>
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<tr>
<td>9:30-11:00</td>
<td>Fourth Session</td>
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<td><strong>Curricula</strong></td>
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<td><strong>Assessment 2</strong></td>
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<td><strong>Transition 2</strong></td>
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<td><strong>Teaching &amp; Learning 3</strong></td>
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<tr>
<td>11:00-11:15</td>
<td>Coffee Break</td>
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<td>11:15-13:15</td>
<td>Fifth session</td>
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<td>• <strong>Curricula 2</strong></td>
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<td><strong>Transition</strong></td>
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<td>13:15-14:30</td>
<td>Guide tour</td>
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<tr>
<td>14:30-16:30</td>
<td>Lunch at restaurant</td>
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<td>“Foxa Molino de Cantarranas”</td>
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<td>Time</td>
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<td>16:30-17:30</td>
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<tr>
<td>17:30-18:30</td>
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<td>19:30-20:00</td>
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<tr>
<td>20:00-23:30</td>
<td>Dinner in the restaurant “Corral de la Moreria”</td>
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<td>Sixth session</td>
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<td>Assessment</td>
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<td>Diversity</td>
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<td>10:30-12:00</td>
<td>Seventh session</td>
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<td>Tools 3</td>
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<td>EER in the UPM</td>
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<td>Lunch</td>
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## Conference Schedule

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### Lunch at restaurant
- **Monday**
- **Wednesday**
- **Friday**

### Coffee Break
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Second Session
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Third Session
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Fourth Session
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Fifth Session
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Sixth Session
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Seventh Session
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### First Session
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Introduction
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Socratic Session
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Journal Editors Sessions
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Guided tour
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Welcome Reception
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Lunch at restaurant
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Bus travel
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**

### Free time
- **Tuesday**
- **Wednesday**
- **Thursday**
- **Friday**
## Conference Session

### Session 1: Wednesday morning

<table>
<thead>
<tr>
<th>SESSION 1 (Wednesday morning)</th>
<th>Threshold Issues Chair: Maura Borrego</th>
<th>Teaching &amp; Learning 1 Chair: Jennifer Turns</th>
<th>Tools 1 Chair: Barbara M. Olds</th>
<th>Learning Strategies 1 Chair: Bill Williams</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:30 – 12:00</td>
<td>97 (Investigating and addressing student difficulties in introductory electrical engineering)</td>
<td>4 (A qualitative inquiry into first year engineering student success)</td>
<td>149 (Instrumental development: Engineering-specific Epistemological/Ontological beliefs)</td>
<td>124 (Engineering learning to Engineering Innovation)</td>
</tr>
<tr>
<td>12:00 – 12:30</td>
<td>102 (Analytical tools in engineering education research - The model of learning a complex concept, threshold concepts and key concepts in understanding of and designing for student learning)</td>
<td>54 (Sharing the past and future in portfolio studios)</td>
<td>76 (Virtual Instruments in dimensional metrology)</td>
<td>85 (A model for evaluation of generic competences in engineering: Application to the problem-solving competence at UPM)</td>
</tr>
<tr>
<td>12:30 – 13:00</td>
<td>49 (Considerations on the academic success in aeronautical engineering studies in Spain)</td>
<td>17 (Engineering student’s conceptions of model uses in design)</td>
<td>105 (An expert-novice study of transfer in an ill-structured problem)</td>
<td>132 (A freshman project based computing engineering course)</td>
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### Session 2: Wednesday afternoon

<table>
<thead>
<tr>
<th>SESSION 2 (Wednesday afternoon)</th>
<th>EER Chair: Llewellyn Mann</th>
<th>PBL Chair: Milo Koretsky</th>
<th>Technology in Learning Chair: Wendy Newstetter</th>
<th>Teaching Practice Chair: Anne Gardner</th>
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</thead>
<tbody>
<tr>
<td>14:30 – 15:00</td>
<td>68 (Strategic pathways to engineering education research; a top-down case study)</td>
<td>28 (Evaluating tutor training for online PBL teamwork courses in first year engineering)</td>
<td>60 (Materials Engineering Degree in the Technical University of Madrid (UPM): The challenges of a new technology)</td>
<td>162 (Want to change learning culture: Provide the opportunity)</td>
</tr>
<tr>
<td>15:00 – 15:30</td>
<td>79 (Hidden barriers to academic staff engaging in Engineering Education Research)</td>
<td>31 (Measuring the influence of cooperative learning and project based learning on problem solving skill)</td>
<td>145 (A new teaching tool on the European space for higher education: Fusion of laboratory and research results)</td>
<td>40 (Are we accidentally misleading students about engineering practice?)</td>
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<tr>
<td>15:30 – 16:00</td>
<td>64 (Analysis of trends in United States National Science Foundation funding for engineering education: 1990 – present)</td>
<td>152 (Reports from teaching practice: experiences and management of tensions encountered with PBL implementations in the early years of undergraduate engineering education)</td>
<td>57 (Computer adaptive testing and the networked model of curriculum in a learning system (MAPI-CAT): The case of Fourier analysis in Computer Engineering in Mexico/engineering education)</td>
<td>22 (Teaching practices of engineering faculty: perceptions and actual practice)</td>
</tr>
<tr>
<td>16:00 – 16:30</td>
<td>144 (A possible resistive electrical circuits learning pathway for engineering students)</td>
<td>87 (Project based learning activities as a means of adapting conventional curricula to the demands of the 21st century aeronautical engineer: The design and building of the EYEFLY)</td>
<td>101 (Virtual 3D support contents oriented to interactive self-learning)</td>
<td>11 (Assessment of generic competences in computing)</td>
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### Session 3: Wednesday afternoon

<table>
<thead>
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<th>TIME</th>
<th>SESSION 3 (Wednesday afternoon)</th>
<th>SESSION 4 (Thursday morning)</th>
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</table>
| 16:45 - 17:15 | **Learning Strategies 2**  
  Chair: Cynthia J. Atman  
  Engagement Chair: Roger Hadgraft  
  Teaching & Learning Chair: Duncan Fraser  
  Knowledge & Leadership Chair: Luis M. Cerdá  
  29 (A variation theory approach to develop learning progressions for engineering concepts)  
  115 (Investigating the characteristics of successful collaborative learning activities)  
  37 (Design-based research as a methodology for investigating learning in the engineering education)  
  44 (Building leadership capacity of engineering academics in a leadership vacuum constructed within a participatory group to engage a professional body)  |
| 17:15 - 17:45 | 153 (First steps in the discovery of patterns in the academic results of telecommunication engineering students in the subjects Analysis of Circuits and Mathematics)  
  65 (Task and networking balance as key to satisfaction with team performance)  
  30 (Investigating the nature of thing orientation)  
  33 (Knowledge management and leadership in the higher education A first approach)  |
| 17:45 - 18:15 | 150 (The influence of engineering education on Optics)  
  78 (Towards technology stewardship: tools for encouraging student engagement)  
  5 (Using Inquiry-Based Activities to Repair Student Misconceptions Related to Heat, Energy and Temperature)  
  70 (Teaching contextual knowledge in engineering education - Theory of Engineering science and the core curriculum at the Technical University of Denmark)  |
| 18:15 - 18:45 | 80 (Development of new teaching activities for learning Robot Mechanics)  
  132 (A freshman project based computing engineering course)  
  94 (Using complexity theory to develop a new model of student retention)  
  122 (Other looks and knowledge for the education in Engineering)  |

### Session 4: Thursday morning

| TIME          | Curricula 1 (Chair: Amparo Camacho)  
  Assessment 1 (Chair: Edith Gummer)  
  Transition 1 (Chair: Robin Clark)  
  Teaching & Learning 3 (Chair: Michael Prince)  | 53 (Assessment as a tool for improving the education of engineers: experiences of international accreditation of the Universidad del Norte)  
  7 (Tool for automatic production and management of written and web test exams)  
  84 (Engineering in an elementary setting: An analysis of context maps)  
  133 (New methodology on applied geology and geology for engineers education by using practical trip)  |
|---------------|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| 09:30 - 10:00 | 89 (Quality assurance in engineering education in Russia)  
  56 (Does the continuous evaluation drive us to the mediocrity?)  
  136 (Conceptual change in precollegue engineering)  
  26 (Competence monitoring in project teams by using web based portfolio management systems)  |
| 10:00 - 10:30 | 161 (Informing engineering education for sustainable development using a deliberative dynamic model for curriculum renewal)  
  9 (An improvement of academic results by a self-study methodology in transportation engineering subject)  
  108 (Forging futures? Engineering in the primary school curriculum)  
  27 (Toward lifelong learning: self-regulation in undergraduate engineering courses)  |
# Session 5: Thursday afternoon

## Curricula 2
**Chair:** Dawn Williams

<table>
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<th>Time</th>
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<tr>
<td>11:00 - 11:30</td>
<td>159 (Studying interdisciplinarity in Engineering degree courses: Conceptual and methodological issues)</td>
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<td>58 (Classroom experiments in the new degree of Materials Engineering at UPM)</td>
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<td>138 (Assessing the Ethical development of engineering undergraduates in the United States)</td>
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<td>116 (Development of learning environments to increase the understanding and interest in engineering and technology amongst Australian primary school students)</td>
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<td>11:30 - 12:00</td>
<td>96 (Facilitating intellectual and personal skills development in engineering programmes)</td>
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<td>91 (An architecture for virtual and remote laboratories to support distance learning)</td>
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<td>154 (Engineering ethics: the state of the art)</td>
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<td>71 (Starting young: Outcomes of a developmentally appropriate preK engineering curriculum)</td>
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<td>12:00 - 12:30</td>
<td>81 (The development of a systematic process to define graduate outcomes for engineering disciplines)</td>
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<td>139 (Improving the learning process in statistical decision-making laboratory)</td>
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<td>36 (Engineering as a caring and empathetic discipline: conceptualizations and comparisons)</td>
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<td>75 (Measuring students’ perceptions of engineers: Validation of the draw-an-engineer (DAET) coding system with Interview Triangulation)</td>
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<td>12:30 - 13:00</td>
<td>88 (The development of assessment tools using phenomenography)</td>
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<td>135 (Low cost 3D Gesture based interface use for engineering lecturing)</td>
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<td>10 (Engineering, learners and contexts (ELC): Development of pedagogical engineering knowledge by elementary teachers through perceived learning and implementing difficulties)</td>
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## Classroom Experiments
**Chair:** Lyn Brodie

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## Ethics & Values
**Chair:** Cynthia Finelli

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## Transition 2
**Chair:** Johannes Strobel

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# Session 6: Friday morning

## Assessment 2
**Chair:** Erik de Graff

<table>
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<th>Time</th>
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<tr>
<td>08:30 - 09:00</td>
<td>123 ((Re-)Building an assessment paradigm: Individual student learning in team-based subjects)</td>
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<tr>
<td>09:00 - 09:30</td>
<td>20 (Methodology for automated generation of multiple choice questions in self assessment)</td>
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<tr>
<td>09:30 - 10:00</td>
<td>179 (Assessing individual performance within group design and group problem solving learning environments)</td>
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<td>10:00 - 10:30</td>
<td>104 (Understanding feedback in an authentic, ill-structured project through discourse analysis: Interaction between student and instructor objectives)</td>
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## Tools 2
**Chair:** James Pellegrino

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<th>Time</th>
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<tr>
<td>08:30 - 09:00</td>
<td>119 (Quality of experience of online learning tools)</td>
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<tr>
<td>09:00 - 09:30</td>
<td>34 (Concept Inventories as aids for instruction: a validity framework with examples of application)</td>
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<tr>
<td>09:30 - 10:00</td>
<td>59 (Laboratory experiments. Case study of a virtual approach)</td>
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<tr>
<td>10:00 - 10:30</td>
<td>158 (An interactive platform for 1A Games)</td>
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## Teaching & Learning 4
**Chair:** Mario Letelier

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<th>Time</th>
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<tbody>
<tr>
<td>08:30 - 09:00</td>
<td>86 (Learning speed evaluation of first year engineering students)</td>
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<tr>
<td>09:00 - 09:30</td>
<td>160 (Negotiation Games: Acquiring skills by playing)</td>
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<tr>
<td>09:30 - 10:00</td>
<td>103 (Shifting conceptions of engineering design: longitudinal and cross-sectional studies of undergraduate engineering majors)</td>
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<td>10:00 - 10:30</td>
<td>8 (Microgenres: Critical “Markers” that can facilitate teaching and assessing student writing within and across Schools or Colleges of Engineering)</td>
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## Diversity
**Chair:** Lorraine Fleming

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<tr>
<th>Time</th>
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<tbody>
<tr>
<td>08:30 - 09:00</td>
<td>42 (Observational research methods to explore intercultural competence in engineering)</td>
</tr>
<tr>
<td>09:00 - 09:30</td>
<td>151 (Does Social Capital Matter? Impacts of social capital on African American male achievement)</td>
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<tr>
<td>09:30 - 10:00</td>
<td>32 (Understanding engineering self-efficacy of students involved with a professional minority engineering society)</td>
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<tr>
<td>10:00 - 10:30</td>
<td>157 (Defining diversity: Impacts on students’ engineering identity)</td>
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### Session 7: Friday morning

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*Presenter: Caroline Baillie*
Proceedings of the conference

1º Session – Wednesday morning

Topic: Threshold Issues – Chair: Maura Borrego

Investigating and addressing student difficulties in introductory electrical engineering

Christian Kautz
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Hamburg University of Technology
German

Abstract: We briefly review some previously published results and present some original data on student understanding in introductory electrical engineering courses. These results indicate that many students do not understand or do not appreciate the model nature of circuit analysis in electrical engineering. Moreover, this lack of understanding or appreciation may affect their performance on standard tasks in circuit analysis, especially those that require a functional understanding of electric potential.

Introduction

At a recent conference, we described an approach to improving instruction in introductory electrical engineering courses that is based on an empirical investigation of student understanding of selected topics (Kautz, 2011). There we presented data on student difficulties with determining phase relationships in AC circuits and gave a description of our instructional materials that appear to help strengthen student understanding of this topic. We observed that students’ incorrect interpretation of the characteristic phase behavior of resistive, inductive, and capacitive elements led them to statements that contradicted a straightforward application of Kirchhoff’s current and voltage laws. From the data, we concluded that the students’ understanding of these circuit laws was often not sufficiently robust to withstand the confounding effect of their difficulties with AC phases.

In our paper, we referred to the theory of threshold concepts as proposed by Meyer and Land (2003) and briefly explored the idea that the existence of two such threshold concepts may account for our observations.

The first of these we conjectured to be electric potential. By failing to recognize electric potential as a property of nodes (or points) in a circuit, some students are unable to identify quantities of common phase among a circuit’s voltages and currents with various phase relationships. At the level of a metaconcept of circuit analysis, we proposed to consider the model itself as a threshold concept. Student failure to interpret circuit diagrams as a graphical representation of a set of mathematical equations may, for
example, enhance their belief that voltage and current in an ideal source are always in phase (Kautz, 2011). Interestingly, it appears as if in this case it is not a lack of connection between model and real-world objects that causes difficulties for many students, as suggested by Carstensen et al. (2005) in the context of a lab activity on transient behavior of electric circuits. Instead, students may make too close a connection between the graphical representation of the mathematical formalism and the real-world objects to which they (perhaps incorrectly) ascribe certain properties.

In this paper, we present further evidence that even after instruction (1) many students have very basic difficulties with electric potential; (2) that they often do not recognize that the content they are expected to learn constitutes a theoretical model with certain rules and assumptions; and (3) that they fail to appreciate that these assumptions may be satisfied to varying degree in a real-life apparatus.

**Modeling aspects of circuit analysis**

A large part of introductory science and engineering instruction can be thought of as the teaching of conceptual and quantitative models of natural and technological phenomena. About twenty years ago, David Hestenes (1992) argued, that “to understand science is to know how scientific models are constructed and validated. The main objective of science instruction should therefore be to teach the modeling game.” In engineering education, this view may not be completely shared, but for students to recognize that the course content largely consists of such models may be necessary for their functional understanding of the material.

The formalism of DC and AC circuit analysis, as it is taught in the first and second semester of several engineering bachelor programs at Hamburg University of Technology, consists of a set of rules that relate measurable physical quantities that can be ascribed to certain physical elements with specified properties. In this linear circuit model, the rules are Kirchhoff’s circuit laws regarding currents (KCL) and voltages (KVL), whereas Ohm’s law and its generalization (U = I·Z) for reactive elements specifies the properties of the elements resistance, inductance, and capacitance. The remaining elements are ideally-conducting connecting wires (U = 0), and voltage or current sources (U = const., and I = const., respectively). While it is mentioned early on that incandescent light bulbs do not obey Ohm’s law, a discussion of non-linear elements usually only takes place in the second semester of the course.

**Context of study**

Our study on student understanding of electric circuit concepts involved students in various first-year electrical engineering courses at two institutions in Hamburg, Germany, as well as students in an electronics laboratory course at an institution in the United States. The data presented in this paper were all obtained in the first semester of two year-long courses for mechanical and naval engineering students (TUHH-ME) or for general and electrical engineering students (TUHH-EE) at our home institution in Germany.
Student understanding of modeling aspects

In order to probe student understanding of the model aspects of DC circuit analysis, we administered two ungraded quiz questions at the beginning of a lecture period well into the final third of the semester. By that time, coverage of DC circuits had been completed and the course had moved on to other topics (AC circuits in TUHH-ME, static electric and magnetic fields in TUHH-EE). A variant of one question was also given as part of a final exam to a different cohort of students in one of the courses (TUHH-ME).

Question on mathematical representation

In one of the questions given to about 300 students in TUHH-ME, the students were shown the circuit diagram in Figure 1. They were then given the following three tasks: (a) to state a mathematical relationship between the electric potentials at points Q and T, (b) to state a mathematical relationship between the currents I_1 and I_2, and between I_1 and I_3, and (c) to decide whether it is possible to insert an additional voltage source U_c between points X and Y (with its arrow pointing down), and to state what values can be chosen for U_c.

We expected students to recognize that for the potentials at points Q and T, the most simple relationship that could be inferred from the diagram (and the only one in terms of the given quantities) involves the voltage source U_B. By the definition of a voltage source (and considering the sign convention used in the course), the correct answer for part (a) would be $V_T - V_Q = U_B$. Similarly, for part (b) one may infer from the definition of a current source and Kirchhoff’s current law (KCL) that $I_1 - I_2 = I_A$ and $I_1 + I_3 = I_A$. In part (c), students needed to recognize that the presence of $U_B$ in the circuit diagram mathematically corresponds to the statement in part (a) above; that a duplication of that statement has no effect on the solvability of the corresponding system of equations; and that therefore an additional source may be added between X and Y as long as it satisfies the condition that $U_c = -U_B$. A more physical argument would be that two ideal batteries (i.e., ideal voltage sources) can be connected in parallel without any resulting change to the circuit.

![Circuit diagram in quiz question on mathematical representation](image)

Figure 1: Circuit diagram in quiz question on mathematical representation

Of the 188 students who gave a non-blank answer to task (a) of this question, about 30% specified a relationship between the potentials at points Q and T involving $U_B$ that was correct apart from possibly a sign error. Most of the remaining answers asserted that one
of the potentials was greater than the other or that they were of equal magnitude. In task (b), not only was there a larger number of nonblank answers given on both parts of this task (about 250 in each case), but also the fraction of correct answers was substantially greater, as close to 50% of the students gave a completely correct answer in the two cases.

From these results we infer that students even at this stage have considerable difficulty interpreting a voltage source in a circuit diagram in terms of a mathematical statement of a potential difference between two points in the diagram. Furthermore, these results indicate that comparable questions about currents are answered by a substantially greater fraction of students. This seems to confirm our claim that of the two concepts, voltage and current, voltage is the one that proves more difficult for most students (Kautz, 2011).

Task (c) was again answered more or less correctly by about 30% of the students, while about 15% stated that inserting an additional source between the specified points was not possible. A surprisingly large fraction of students (slightly more than 20%) stated that the value of the added source either had to be greater or that it had to be less than that of the existing source. While we could not gain much insight into the students’ reasoning from their answers, we suspect that students felt that one of the sources had to be, in some sense, "stronger" than the other. It is possible that students were trying to imagine the behavior of real batteries as they answered this question. We are hoping to get a better understanding of student reasoning about this issue through interviews with individual students.

Questions on applicability of model assumptions

*Quiz question:* In another quiz question, the students were shown the circuit diagram in Figure 2, in which a battery was connected to a parallel circuit consisting of one branch with two light bulbs and another with a single bulb. All bulbs were given to be identical and the connecting wires were to be considered ideally conducting (as is the general assumption for lines in a circuit diagram). However, two statements were made about possible limitations to the usual idealizations implicit in the model: (i) It was stated as unknown whether the battery could or could not be considered an ideal voltage source. (ii) The I-U characteristic of the bulbs was stated as "unknown". As part of the problem description, outcomes of two measurements were given to the students: The current through bulb B (the lower bulb in the series circuit) was given as $I_B = 0.3 \text{ A}$; the current through bulb C (the one in the single-bulb branch on the right) as $I_C = 0.5 \text{ A}$. The students were then given the following three tasks: (a) to determine the current $I_A$ through bulb A, (b) to determine the voltage $U_A$ across bulb A relative to that across bulb C, and (c) to decide whether either of two statements could be inferred from the given data: Statement X, that the battery behaved as a non-ideal voltage source (i.e. that it had a non-vanishing internal resistance, or $R_i > 0$), or statement Y, that the I-U characteristic of the bulbs is nonlinear (i.e. that current and voltage are not proportional).

The current readings given to the students in this question were realistic values for miniature incandescent bulbs but did not correspond to the values obtained if equal resistances for the three bulbs were assumed. One purpose of the first two tasks, however,
was to check whether students were able to apply Kirchhoff’s current and voltage laws in the presence of some irrelevant and possibly confusing information. For a correct answer, the students simply needed to infer $I_A = I_B = 0.3$ A from KCL, and $U_A = 0.5$ $U_C$ from KVL and the fact that bulbs A and B are identical. While our main interest was how well students would do on task (c), we wanted to know the number of students who answered the previous two tasks correctly as a baseline for interpreting this result. For task (c), students needed to check the validity of the inference from the given data for each statement separately. In order to do so for statement X, they needed to recognize that data for a single load (i.e. a single point on the load line) was not sufficient to conclude whether the battery could be considered an ideal source or not. As for statement Y, however, a comparison of the resistances (i.e. the ratios of voltage to current) for bulb A (or B) and bulb C was possible and yielded different outcomes (0.5 $U_C$/ 0.3 A versus $U_C$/0.5 A), thereby allowing the conclusion that statement Y was indeed correct.

All three tasks were given in multiple-choice format with an (open-ended) request to explain the reasoning used. In task (a) the distracters were 0.2 A (i.e. $I_C - I_B$) and 0.5 A (i.e. $I_C$), as well as the range between these values (but ≠ 0.3 A) and the statement that an answer was not possible. In task (b) the distracters were “less than 0.5 $U_C$“, “between 0.5 $U_C$ and $U_C$”, “equal to $U_C$“, and “greater than $U_C$“. In task (c) the four choices were “statement X”, “statement Y”, “both statements”, or “neither”.

Of the 314 students who participated in the quiz, about 82% correctly determined the current through bulb A (task (a)). About 50% of the students correctly compared the voltage across bulb A to that across bulb C (task (b)). Of the students who answered both these tasks correctly (corresponding to 46% of the total), about a quarter (23%) decided that only statement Y could be inferred from the data presented. An additional 14% did so for statements X and Y. Unfortunately, only about a third of the students gave an explanation for their answers. Very roughly about half of the explanations associated with the correct answer accounted for the different ratios for voltage and current in a way that could be interpreted as correct. Most of the others, as well as most of the explanations associated with incorrect answers, referred to statements X and Y as facts that they had learned to be generally true or untrue. It may be said that these students misinterpreted
the question that was asked. However, this in itself is an interesting result as these students seemed to be lacking an understanding that the methods of circuit analysis they had studied were based on certain assumptions and that the degree to which these assumptions are satisfied by real-world objects could be tested empirically.

**Examination question:** The second of the two quiz questions was also given as part of the final examination to a different cohort of the same course (TUHH-ME). Tasks (a) and (b) were reversed in order, i.e. the question about voltage was asked first. To simplify the grading process, the question was given in a pure multiple-choice format; no explanation of student reasoning was asked for.

When given as part of the examination, the three tasks yielded results that were quite similar to those obtained in the ungraded quiz. The task about the voltage across bulb A (now in first place) was answered correctly by 52% of the students (versus 50% on the quiz); that about the current through the same bulb by 90% (versus 82%). The percentages of students giving a correct or partly correct answer to task (c) were again very similar, with 26% correctly choosing only statement Y and an additional 10% choosing statements X and Y (versus 23% and 14%), as a fraction of those answering (a) and (b) correctly in both instances.

We take the results of the examination question to confirm the results of the quiz question shown above. From a methodological point of view, this indicates (in agreement with prior experience) that even ungraded quizzes can yield reliable data on student knowledge and understanding. The slight increase of student success on the most straightforward of the questions asked (90% versus 82% correct answers about currents in series) may likely be due to the effect of studying for final exams. Both results consistently show, however, that questions about the assumptions of the linear circuit model, especially those that involve reasoning with observed or given experimental data, remain very difficult for the students.

**Conclusions**

While all the questions administered to the students as part of an ungraded quiz or examination were considered “fair game” by the respective instructors, we are aware of the fact that both types of the questions shown here are non-standard. Apart from a brief interlude in one lecture during which various modeling aspects were introduced, this topic was not discussed in the course. We may then conclude that if as instructors of circuit analysis we want students to gain a functional understanding of the course content as a mathematical model for real-world circuits, the relationship between these two “worlds” has to be made explicit. It is in this sense that we agree with some of the conclusions put forward a few years ago by Carstensen and Bernhard (2007). Our results not only indicate that many students do not understand or do not appreciate the "model" nature of the linear circuit model in electrical engineering. On the basis of the results of our first question above, we also believe that this lack of understanding or appreciation actually hampers their performance on more traditional tasks in circuit analysis, especially those that require a functional understanding of electric potential.
Due to the limitations of the instruments used – in some cases multiple-choice tasks with an open-ended request for explanations that the students may have considered optional – we were unable to obtain an very accurate picture of student thinking. Further research on student understanding of modelling aspects is warranted. We are currently planning individual student interviews to probe their understanding of these issues more deeply.

Finally, we believe that these results will have implications for the teaching of electric circuits and other subjects in introductory engineering. From the work of Hestenes (1992) a successful approach to teaching physics that emphasizes a modelling approach has been developed (Brewe, 2008). Our own observations in engineering mechanics suggest that the notion of a theoretical “model” to describe real-world objects (beams, trusses, etc.) plays an important role there as well. In future work, we would like to bring results from both these strands of research together.

References


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Analytical tools in engineering education research: The “learning a complex concept” model, threshold concepts and key concepts in understanding and designing for student learning.

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Abstract: For a long time, most research relating to science and engineering education has examined “misconceptions” about “single concepts”, despite the fact that one common objective in many subjects is “to learn relationships”. In this paper we introduce the notion of “a complex concept”, i.e. the idea of describing knowledge as a complex, a holistic unit, consisting of interdependent and interrelated “single concepts”. We describe how this conception could be used to identify both problems associated with learning as well potentials for learning. We will also relate the notion of a complex concept to the notion of threshold and key concepts.

Introduction

In recent years there has been increasing research into the critical factors associated with learning within engineering education; indeed, the engineering education research (EER) field has started to mature (cf. Baillie & Bernhard, 2009; Borrego & Bernhard, 2011). Within EER there has been little explicit discussion of the issue of methodology (cf. Case & Light, 2011). Any such discussion should be closely intertwined with theoretical perspectives and the selected epistemology. As succinctly stated by Marton and Pang (2008, p. 543), we must start with the questions why? and what? (e.g. Borrego & Bernhard, 2011; Melezinek, 1977) and “first of all, [ask] what kind of capability do we want [students] to nurture?” In both engineering and physics education, a common objective is that students should learn to use theories and models in order to understand the relationship between theories and models, and objects and events, and to develop holistic, conceptual knowledge. Engineering students are expected to use, or learn to use, symbolic and physical tools (such as concepts, theories, models, representations, inscriptions, mathematics, instruments and devices) in order both to understand the phenomena being studied, and to develop the skills and abilities to use the tools themselves to solve real-
world engineering problems. Rorty’s (1991) statement that knowledge is not “a matter of getting reality right, but a matter of acquiring habits of action for coping with reality” and Marton and co-worker’s statement that knowledge is a “capability of handling novel situations in powerful ways” (Marton, Runesson, & Tsui, 2004, p. 5) quite accurately describe important aims associated with engineering students’ learning.

However, EER has been inspired by longer-established research traditions, such as science education research (cf. Fensham, 2004). But engineering epistemology differs from that of science as noted, for example, by Henryk Skolimowski (1966): “science concerns itself with what is, technology with what is to be” (p. 375, italics in the original). Hence there are differences in epistemology and consequently in the object of learning (Runesson & Marton, 2002) that should be reflected in the methodologies used in EER (cf. González Sampayo, 2006). A necessary condition for learning, as noted by Ference Marton and his co-workers (Marton & Booth, 1997; Marton & Tsui, 2004), is that students must be able to focus on the ‘object of learning’ and discern its critical features. They note that the ‘object of learning’ is not a ‘thing’, but a set of relationships, concepts, theories, capabilities etc., that the students are supposed to learn (the intended object of learning). The critical aspects of the object of learning must enter the focal awareness of students. In their work they also pointed out that

“people act ... in relation to situations as they perceive, experience, and understand them. ... If we want learners to develop certain capabilities, we must make it possible for them to develop a certain way of seeing or experiencing. Consequently, arranging for learning implies arranging for developing learners’ ways of seeing or experiencing, i.e., developing the eyes through which the world is perceived” (Marton, et al., 2004).

Hence, the development of capabilities (cf. Bowden, 2004) is important in engineering education. To achieve this requires developing “learners’ ways of seeing and experiencing” and following, for example, Dewey (1925/1981, 1938/1986) and Wells (2008), whose concepts should be considered to be “...tools for making sense of the world around us, or tools ‘to see with’” (Marton & Pang, 2008, p. 543). Students and experienced engineers use artefacts, i.e. symbolic tools (concepts) as well as physical tools, to “see with” (Bernhard, in press).

The “learning of a complex concept”

The model

In education research, for example in science education research, it is common to investigate “misconceptions” about “single concepts”. However, when we analysed engineering students’ learning during a course on electric circuit theory, we found that examining student learning in terms of “single concepts” was not sufficient. As a result, the notion that learning should be seen as the learning of a complex concept, i.e. a “concept” that makes up a holistic system of “single” interrelated “concepts” (a whole made up of interrelated parts) emerged (e.g. Bernhard, Carstensen, & Holmberg, 2010; Carstensen &
Bernhard, 2004, 2008; Carstensen, Degerman, & Bernhard, 2005). Below we introduce the ideas behind our model of learning as the “learning of a complex concept” and demonstrate some of the power of this analytical tool.

In our model “single concepts” are illustrated as nodes or “islands” that may be connected by links, while the links students actually make (identified by analysing the lived object of learning, i.e. what students actually learn, using empirical data such as video-recordings), or are supposed to make (identified by analysing the intended object of learning), are represented by arrows. The nodes in our model can be found empirically, by looking for “gaps” (Wickman, 2004) in the actions and dialogue of students. A gap corresponds to a link that has not been established, and when a gap is filled and the students establish a relationship between two nodes, this is represented by a link (a generalised version of the model is presented in figure 1b). This methodology is a further development of Wickman’s (2004) practical epistemologies, which were based on Wittgenstein’s (1953/2003) philosophy of language.

The idea behind our model is that knowledge is holistic. Knowledge is built by learning the component pieces, the islands, as well as by learning the whole object of learning through making explicit links. Hence, the more links that are made, the more complete the knowledge becomes. It is important to note that we have analyzed the use of concepts, models, representations and experimental equipment (cf. Airey & Linder, 2009; Wells, 2008). Hence, we did not study, or attempt to draw any conclusions about students’ eventual mental models. We studied what students do.

This study is part of a larger piece of research (Bernhard, 2010). We have, over several academic years, studied laboratory work carried out during a first year university level course in electric circuit theory for engineering students (Carstensen & Bernhard, 2004, 2007, 2008, 2009). Using digital camcorders, students’ courses of action have been recorded. In this study we present an analysis of the course of actions of one laboratory group (two male engineering students) in two 4 h lab sessions on electric circuit theory. For this, we use the analysis model briefly presented above. The lab sessions analysed both concerned AC-electricity. The topic of the first was learning to use phasors (the jω-method) in analysing and representing currents and voltages in AC-circuits. The topic of the second lab was analysing the frequency dependency of currents and voltages in AC-circuits and representing these using transfer functions and Bode plots. The results from these two AC-electricity labs are compared with the results from a 2×4 h lab sequence, from the same course and year, the topic of which was transient response (Carstensen & Bernhard, 2004, 2007, 2008, 2009; Carstensen, Degerman, González Sampayo, & Bernhard, 2005).

Results

In figure 1 we present an analysis of the courses of action of two male engineering students’ (Adam and David) in the AC-electricity laboratory sessions. The situation 29 minutes into the session is presented in figure 1 a. Adam and David have established links (although only uni-directional) between the circuit diagram, real circuit and measured
graphs (time-domain). The students are about to establish the link between measured graphs (time-domain) and the complex-valued phasor representation.

Figure 1: For analytical purposes, the shaded circles are attributed to the object/event world and the unshaded circles represent the theory/model world (Tiberghien, 1998; Vince & Tiberghien, 2002). Established links are represented by a solid black arrow and those in the process of being established by a dashed arrow. The “single concepts” that the students have become aware of are represented by black circles and those that they have not by grey circles. a) An analysis of student learning in the first AC-electricity lab. The figure shows Adam and David’s lived object of learning 29 minutes into the session. b) Adam and David’s lived object of learning at the end of the AC-electricity lab. c) Adam and David’s lived object of learning at the end of the frequency dependency lab.

During the next 10 minutes the students struggle with this link and it is not fully established until 42 minutes into the session. The links that Adam and David have identified and the “single concepts” that have appeared after 4 h are presented in figure 1 b. It should be noted that differential equation has appeared as a “single concept” but no links to this concept have been made. Also it is noteworthy that, although the students were asked to establish links to functions in the time-domain, at this stage it does not even appear as an isolated “single concept” in our data.

In the frequency dependency lab, the picture is more complex. In this lab students are supposed to use concepts and representations related to the time-domain as well as the frequency-domain. Several links have been established by the end of the lab, as displayed in figure 1 c. Although calculated graphs in the time domain and functions in the time-domain do appear as “single concepts” no links have been made, nor have there been any attempts to make such links. The reason for this, and the similar result with respect to functions in the time-domain in figures 1 a–b, is that Adam and David did not follow the instructions provided and decided that they could do this later at home.

An analysis of the lived object of learning at the end of the later lab about transient response showed that the “single concepts” circuit diagram and real circuit presented in figures 1 a–c had fused into a single real circuit “concept” (Bernhard, et al., 2010; Carstensen & Bernhard, 2008, 2009). The initiation of this fusion process was already apparent during the previous sessions. In our analysis of the videotapes we noted that, during the first AC-electricity lab, the “gap” between the circuit diagram and the real circuit became less and less apparent as the session went on. In the frequency dependency lab, the fusion process had gone so far that, on many occasions, it was difficult, in our analysis of students’ courses of actions, to determine if links were being made to the
circuit diagram or the real circuit. Our interpretation of this process of fusion is discussed further below.

Discussion

Our studies show the feasibility of using the model of learning a complex concept as an analytical tool in studying student learning in labs. The model facilitates analysis of longer sequences of videorecordings that would otherwise be difficult to summarise and overview. It should be noted that the model is circular, not hierarchical (as most models are), allowing linking across the circle. The model learning a complex concept reveals and illustrates the complexity of knowledge.

In contrast, it is common in education research to investigate “misconceptions” about “single concepts”. In our view this is problematic since these “single concepts” do not, in fact, exist in isolation. In electric circuit theory, for example, the “concepts” of current, voltage and impedance are interdependent. Rather, the central physical phenomenon is “electricity” represented by a generalised Ohms law, which models the current/voltage/impedance/frequency-relationship of a circuit or circuit element. In the thesis of M. Holmberg (González Sampayo, 2006) it was argued that some problems associated with learning electric circuit theory may be due to the common failure to appreciate that concepts should be seen as relationships.

Our results suggest that it is not sufficient to discuss knowledge as a dichotomy between theoretical knowledge and knowledge of the “real world”. The result that the measured graph, calculated graph and the time-function (see figures 1 a–c) were seen, by students, as separate “entities” was found empirically in our data. For an expert in the field these “entities” would in most cases be fused into one “entity”. However, for the students the links between these “entities” were among the most difficult to establish. In our observations we found that the circuit diagram and the real circuit became fused into a single common entity. This suggests that learning a complex concept starts by establishing more and more links. As links become well established, “entities” that have been separate fuse into a whole. Our model provides a method for identifying “learning difficulties”, since these correspond to “gaps” and non-established links. As teachers and experts in a field, we often fail to notice these since, for us, the ‘complex concept’ has become a conceptual whole and we may no longer be able to distinguish the constituent parts. Another conclusion is that it is not sufficient to discuss knowledge in terms of a dichotomy between knowing and not knowing.

N. Bohr (1958) suggested that we should use the word “phenomenon exclusively to refer to the observations obtained under specified circumstances, including an account of the whole experimental arrangement” and he also argued that “it is … impossible to distinguish sharply between the phenomena themselves and their conscious perception”. The model of learning a complex concept describes how students use different tools, physical as well as conceptual, “to see with” and with which to make sense of the world. Thus our model represents what is called a material-discursive practice by Barad (2007) and material hermeneutics by Ihde (2009).
Threshold concepts and key concepts

Previously, we proposed the idea of key concepts – concepts that constitute a "bridge to the learning of other concepts" (Carstensen & Bernhard, 2002, 2008). Closely related to our ideas of key and complex concepts is the newly emergent theory of threshold concepts. A threshold concept represents a transformed way of understanding something without which the learner cannot progress. It entails a shift in learner subjectivity and makes possible extended use of the relevant discourse. Threshold concepts are, according to Meyer and Land (Land, Meyer, & Smith, 2008; Meyer, & Land, 2006), transformative, irreversible and integrative. According to Meyer and Land (2006) the "integrative [aspect of threshold concepts] ... exposes ... interrelatedness of something". The idea behind the notion of a complex concept is to re-present the interrelatedness of "single concepts", i.e. to re-present a conceptual whole. Thus "threshold concepts" and "complex concepts" have some similar features.

Threshold concepts are of special importance, since a deep understanding of them is necessary to facilitate learning other concepts. Examples previously investigated include recursive functions in computer engineering (Booth, 2004), and opportunity cost in economics (Davies, 2006). Both of these are difficult to learn, and if they are not understood thoroughly, they will hinder students understanding of subsequent topics. In our research we found ‘transient response’ to be a threshold concept (Carstensen & Bernhard, 2008), but we also identified the importance of ‘critical aspects’, aspects that must vary systematically, through variation theory (Marton & Tsui, 2004). Previously, therefore, we suggested a distinction between 'threshold concepts and 'key concepts' (Carstensen & Bernhard, 2002, 2008), not in the sense that the term is often used in educational contexts, as being interchangeable with ‘core’ concepts, and meaning simply that the concepts are an important part of the prescribed syllabus. We use the term as a more precise metaphor to mean that the concept in question acts like a key to unlock the ‘portal’ of understanding, the ‘portal’ which opens up to allow learning other concepts.

Conclusion

Our model, 'the model of learning a complex concept', can be used in three different ways: first, to identify what is troublesome for the students when they are learning; second, to find out what needs to be changed in order facilitate learning; and third, to identify changes in students' actions.

New analytical tools for use in research allow us to see things in a new way. We consider that the notions of learning complex concepts, threshold concepts and key concepts are important theoretical and methodological tools in engineering education research, reflecting the skills that engineering students are supposed to learn. We consider that the EER-community should not only import research tools and methodologies from other branches of educational research but also start to develop methodologies of its own that are related specifically to engineering learning. A further development and integration of these (and other) tools would be valuable as part of a critical discussion and further evolution of EER methodologies. This paper is just one contribution to this.
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Methodology for automated generation of multiple choice questions in self-assessment

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Abstract: Current trends in the European Higher Education Area (EHEA) are moving towards the continuous evaluation of the students in substitution of the traditional evaluation based on a single test or exam. This fact and the increase in the number of students during last years in Engineering Schools, requires to modify evaluation procedures making them compatible with the educational and research activities. This work presents a methodology for the automatic generation of questions. These questions can be used as self-assessment questions by the student and/or as queries by the teacher. The proposed approach is based on the utilization of parametric questions, formulated as multiple choice questions and generated and supported by the utilization of common programs of data sheets and word processors. Through this approach, every teacher can apply the proposed methodology without the use of programs or tools different from those normally used in his/her daily activity.

Introduction - overall layout

Subjects with a strong technological character inevitably require examples of application and problem solving for the achievement of educational goals with minimum levels of quality (Kolmos and Graaff, 2003). However, the time dedicated to practical samples resolution is low compared to time spent teaching of theoretical concepts as evidenced the surveys carried out among students in their final years of engineering studies (Sanz, 2010). This situation is aggravated by the implementation of the basic principles which underpin the European High Education Area (EHEA, 1999) setting a trend towards continuous assessment of the student in substitution of other assessment methods traditionally used such as semester tests. Furthermore, in the case of the ETSI Aeronautics of the Polytechnic University of Madrid, the number of undergraduate students is increased significantly due to the join in a single degree the skills provided from two separate degree programs: the degrees of medium grade and the first cycle of higher grade degrees.
This situation leads to the need to provide students with a sufficiently large number of practical applications of the theory, all of them with different solutions in a way that allow students to base their skills accordingly to their needs and their rhythm of work and study. The number of questions will depend principally on the knowledge, skills and study habits of each student, so cannot be fixed at a certain value. In the attempt to satisfy this request, there is a risk of creating "collections of problems" in which the student learns to solve problems-type in an automatic way without too much reflection, hoping to be able to identify the statements presented in the evaluation tests with one of these problems-type. The experience of the authors advised against the creation of such kind of collections, since, even resulting "comfortable" for students and even producing satisfactory academic progress, lead to a kind of learning opposite to professional reality requirements where rarely appear problems type.

To avoid falling in the aforementioned error, there is the need to generate and manage a relatively large number of different exercises, maintaining a similar difficulty level in all of them. This paper aims to provide a method that allows the teacher to organize and manage a significantly high number of implementation issues, using for this purpose common work resources such as spreadsheets and word processors and all oriented the diffusion of the questions using a b-learning platform. It may seem at first glance, that the approach proposed is already solved, as the b-learning platforms provide editing tools for the generation of questions of practical application (Lawrence, 2009), however when the number of such questions increases and reaches the value of thousands, editing and management tools through their own platform becomes almost impossible. For example, for the next course 2010-2011, the number of self assessment questions that have been developed are around 8000. This is certainly a point to resolve while not the only one. Indeed, it is also necessary to choose the way students access to the questions and establish a standard procedure that allows the generation of a sufficiently large number and variety of questions. (Rice and Smith Nash, 2010).

Structure

In order to establish a theoretical framework, below the theoretical concepts that will be used are proposed. The questions of practical application purpose of this study pose problems or exercises with a numerical solution, although, as will be seen, the proposed methodology is also applicable to non-numerical resolution issues.

The formulation of the questions is performed in "parametric form". A parametric question is a question whose formulation contains one or more variable elements or parameters. For example, suppose you are working on the study of parabolic motion and ask the following question based on Figure 1.
"What would be the horizontal distance travelled by a baseball, after being batted, is impelled at a speed of 70 km/h, if the angle at which the batter hits it is 30 degrees?". This question can be redefined using as parameters the values of speed $\textbf{P}_1$ and $\textbf{P}_2$ angle, so the question parametric mode enunciate as "What is the horizontal distance travelled by a baseball, after being batted is impelled at a speed of $\textbf{P}_1$ km / h, if the angle at which hits the batter is $\textbf{P}_2$ degrees?". Parameterization is not necessarily limited to numerical parameters and thus, for example, the question can be parameterized also the units of measure in the form "What is the horizontal distance travelled by a baseball after being batted is impelled to $\textbf{P}_3$ $\textbf{P}_1$ speed if the angle at which hits the batter is $\textbf{P}_2$ $\textbf{P}_4$?".

Setting out the questions requires the use of a b-learning platform. There are several platforms that allow this like Moodle, Blackboard or WebCT among others.

**Methodology**

For numerical applications and without prejudice to other alternatives, the two alternatives considered most appropriate to pose the questions are the *numerical answer* and the *alternative answer*. The proposed methodology can be described through the stages represented in Figure 2.
Figure 2: Methodology types

*Question parameterization*: stage that defines the variable values (parameters of a statement) and their ranges of variation. These ranges may be continuous or discrete; the latter is the most suitable for the generation of self-evaluation exercises.

*Parametric resolution*: at this stage the exercise must be resolved for all combinations of values of parameters defined in the previous step. To do this, it is very appropriate to use a spreadsheet in which each field corresponds to a variable in the question and each record to a complete question.

*Alternatives generation*: at this stage alternative responses are generated. Only it’s being done if multiple choice questions is used as method of spread results.

*Questionnaires creation and maintenance*: at this stage, the issue is created and, using the combination of text options, questions are generated. It also includes management and the questions maintenance.

*Results spreading and evaluation*: At this stage, the contents of the previously created and selected issues is distributed to students

**Results**

In order to validate the proposed methodology, we present the results, applied to the example of the baseball batter described in "Structure" paragraph.

*Question parameterization*: Velocity values ($v$), angle of batting ($\alpha$) and speed units ($v_{\text{units}}$) are the selected parameters. The range of each parameter are the integer values
$v = \{70, \ldots, 100\}$, $\alpha = \{20, \ldots, 50\}$ and the units $v_{units} = \{\text{m/s, km/h}\}$. In these circumstances it would have a total of $31 \times 31 \times 2 = 1922$ possible variants.

**Parametric resolution:** A spreadsheet is used. The formulas that allow the resolution of the problem are $t = \frac{2}{9.8} v_0 \sin \alpha$ and $d = v_0 \cos \alpha t$, where $t$ is the time that the ball is in motion and $d$ represents the horizontal distance expressed in meters. The spreadsheet will look exactly as shown in Table 1, where $Q_1$, $Q_2$ and $Q_3$ represent numerical examples, $\text{Vars}$ represents the variables used in the example (parameters and intermediate or final results) and $\text{Formulae}$ represents the formulas used. The existence of auxiliary parameters such as $\text{random}$, $v_{ms}$ or $\text{time}$ helps the resolution of the exercise or allows to choice between several options.

**Table 1:** Sample parametric resolution

<table>
<thead>
<tr>
<th>(*)</th>
<th>Vars</th>
<th>Formulae</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
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<td>A</td>
<td>random</td>
<td>=RANDBETWEEN (0;1)</td>
<td>15</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>$v$ =IF(random=0;RANDBETWEEN(3;10)*5;RANDBETWEEN(5;15)*10)</td>
<td>100</td>
<td>140</td>
<td>20</td>
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<td>C</td>
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<td>km/h</td>
<td>km/h</td>
<td>m/s</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>$v_{ms}$ =ROUND(IF($v_{units}&quot;m/s&quot;;83.85/3.6;2))</td>
<td>27.78</td>
<td>38.89</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>$\alpha$ = RANDBETWEEN (2;16)*5</td>
<td>75</td>
<td>50</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>$\text{time}$ =ROUND(2* $v_{ms}$ *$\sin \alpha$</td>
<td>5.5</td>
<td>6.1</td>
<td>3.8</td>
<td></td>
</tr>
</tbody>
</table>

(*) To provide a clearer representation, the order between rows and columns into Table 1 has been transposed regarding their normal distribution in spreadsheets.

Table 1 also shows common functions of spreadsheets. These are PI () representing the relationship between the length and diameter of a circle, RANDBETWEEN () that provides a random value on the interval described, ROUND () that rounds a value to a certain number of decimals, IF () to choose between two values out from a condition and SIN () and COS () that are the trigonometric functions of sine and cosine. For more information any book about spreadsheets like (Albright and Winston, 2004) can be consulted. Once the exercise is solved in one row for the first parametric case, the rest of the questions are immediately got by scrolling the solved case until the desired number of questions.

**Alternatives generation:** If the question is formulated requesting a numerical answer is not necessary to generate alternatives, but when the question is formulated in the way of multiple choice questions, the generation of alternatives becomes a very important role in the success of the approach. In this case, it is necessary to define, in addition to the solution, alternative answers that are "credible". To do this, the choose of the numerical values in alternative responses must be taken with care because if not, it is possible to generate some kind of pattern in the answers that would achieve the correct answer without solving the proposed problem.
Table 2: Sample alternative generation

| (*) This table contents the continuation of the spreadsheet in Table 1 showed using the same layout |

<table>
<thead>
<tr>
<th>Vars</th>
<th>Formulae</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>distance</td>
<td>=ROUND(time * COS(alpha * PI()/180) * v_ms;1)</td>
<td>39.5</td>
<td>152.5</td>
</tr>
<tr>
<td>H</td>
<td>offset</td>
<td>=RANDBETWEEN(-1;1)</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>I</td>
<td>inc</td>
<td>=ROUND(distance /10;1)</td>
<td>4</td>
<td>15.3</td>
</tr>
<tr>
<td>J</td>
<td>R1</td>
<td>=distance -2* inc + offset -2* inc</td>
<td>23.5</td>
<td>121.9</td>
</tr>
<tr>
<td>K</td>
<td>R2</td>
<td>=R1+ inc</td>
<td>27.5</td>
<td>137.2</td>
</tr>
<tr>
<td>L</td>
<td>R3</td>
<td>=R2+ inc</td>
<td>31.5</td>
<td>152.5</td>
</tr>
<tr>
<td>M</td>
<td>R4</td>
<td>=R3+ inc</td>
<td>35.5</td>
<td>167.8</td>
</tr>
<tr>
<td>N</td>
<td>R5</td>
<td>=R4+ inc</td>
<td>39.5</td>
<td>183.1</td>
</tr>
<tr>
<td>O</td>
<td>p1</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>P</td>
<td>p2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Q</td>
<td>p3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>R</td>
<td>p4</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>S</td>
<td>ra</td>
<td>=ROUND(choose(p1;R1;R2;R3;R4;R5);1)</td>
<td>39.5</td>
<td>183.1</td>
</tr>
<tr>
<td>T</td>
<td>rb</td>
<td>=ROUND(choose(p2;R1;R2;R3;R4;R5);1)</td>
<td>23.5</td>
<td>121.9</td>
</tr>
<tr>
<td>U</td>
<td>rc</td>
<td>=ROUND(choose(p3;R1;R2;R3;R4;R5);1)</td>
<td>31.5</td>
<td>152.5</td>
</tr>
<tr>
<td>V</td>
<td>rd</td>
<td>=ROUND(choose(p4;R1;R2;R3;R4;R5);1)</td>
<td>27.5</td>
<td>137.2</td>
</tr>
<tr>
<td>W</td>
<td>TF ra</td>
<td>=IF(ra=distance;TRUE;FALSE)</td>
<td>TRUE</td>
<td>FALSE</td>
</tr>
<tr>
<td>X</td>
<td>TF rb</td>
<td>=IF(rb=distance;TRUE;FALSE)</td>
<td>FALSE</td>
<td>FALSE</td>
</tr>
<tr>
<td>Y</td>
<td>TF rc</td>
<td>=IF(rc=distance;TRUE;FALSE)</td>
<td>FALSE</td>
<td>TRUE</td>
</tr>
<tr>
<td>Z</td>
<td>TF rd</td>
<td>=IF(rd=distance;TRUE;FALSE)</td>
<td>FALSE</td>
<td>FALSE</td>
</tr>
</tbody>
</table>

For example, if the correct solution is a certain numerical value, and as alternative answers are used this number plus a random value and this number less a random value, the student will end up detecting that the correct answer is one whose numerical value is located in the center position. In this case he/she doesn’t know how to solve the exercise to get the correct answer. If this same case is used as an alternative response "none of the other three" the resolution is not as obvious because it is possible that the central value was also incorrect. However, the probability to guess the correct answer will always be greater when choosing the central value.

One possible way to solve this problem is to generate a number n of responses greater than the number m of alternatives offered in the question and randomly select m-1 alternatives with the correct answer. At same time, the generation of alternatives must be made in a way that the correct value occupies a random position with respect the other values because, otherwise, an alternative numerical centered with respect to other two, always have a higher probability of being the correct answer. This is achieved fixing a random value that defines the alternative with the lowest numerical value and a successive increase that generates the alternative values. Continuing with the example presented, the obtained results are given in Table 2. It can be observed how to five random responses (n = 5), have been generated. These are designated as R1 to R5. Fields p1 to p4 contain a random combination of n elements taken from m in m, and are used as variables for the random choice of the m responses (m = 4) by the function CHOOSE (). These
responses appear in the fields ra, rb, rc and rd with the corresponding results TRUE/FALSE in the fields TF_ra, TF_rb, TF_rc and TF_rd.

**Questionnaires creation and maintenance:** To generate the questionnaire from the spreadsheet it is necessary to create a template which present each questions generated, with the text and the desired format. The template should be generated in a word processor that allows merging between text and spreadsheet data. The creation of the questionnaire will consist of writing the text and combining it with the corresponding fields in the spreadsheet. Figure 3 contains the template created for the sample.

![Figure 3: Questions' template](image)

It shows, in bold, the merged fields that correspond to fields from the spreadsheet. Also, appear in bold two delimitation characters "{" and "}". Both are necessary to separate the question body from responses. Finally, the character → appears representing a tab.

**Results spreading and evaluation:** To carry out this step is necessary to use a platform b-learning. The combination of the above will have generated a number of issues equal to the number of rows with data from the spreadsheet. To incorporate all of these issues automatically to the platform should generate a file with one of the formats of import and export of questions.

![Figure 4: Two questions in GIFT format](image)

Although there are several formats, it was considered that the format GIFT (GIFT, 2011) is very appropriate for its versatility and its wide diffusion among b-learning platforms. If the template has been generated in accordance with established rules in the previous section, to obtain the battery of questions in GIFT format is immediate from the merged file. It is sufficient to replace terms "TRUE" and "FALSE" by the characters "+" and "+" (ASCII 126) respectively. The result is shown in Figure 4. Finally, GIFT file can be imported
into b-learning platform, obtaining a result as shown in Figure 5, which has been copied from Moodle platform at Polytechnic University.

![Image of a question in Moodle platform](image.png)

**Figure 5: Final view in b-learning platform**

### Conclusions

The generation of helping tools for questionnaires is a widespread idea throughout the educational community (Itkonen, 2006). Nevertheless, and despite the existence of simple solutions for the forms generations, no one of them has got a system to automate easily the creation of questions and answers arrays. The main contribution of the presented work is to provide an automatic method of generation of large number of questions using standard tools and without the need of using more complex applications. It is also proposed a method of storage and manage the questions, which again, using common tools that can be undertaken quickly and easily. In this way, engineering students have a sufficiently large number of application exercises which allow carrying out, according to their own necessities, the consolidation of acquired knowledge and self-assessment of their learning without compromising the time required for teaching of theoretical content. In addition to the use of guided repetition as a teaching technique, the high number of questions provides a tool to prevent, reduce and even eliminate cheating (Jeschofnig, 2011). Finally it should be remarked that proposed methodology has been implemented at ETSI Aeronautics in Polytechnic University since last year. Although it is premature to make an assessment, impressions received from students and teachers involved have been very positive.

### References


GIFT (2011) [http://docs.moodle.org/en/GIFT_format](http://docs.moodle.org/en/GIFT_format)


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A qualitative inquiry into first year engineering student success

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Abstract: Student success, drop out and progress are hot issues in most schools of engineering. The problem of high drop out has been looked at many times, with researchers using similar dependent variables like progress, grade point average or persistence. In this study we explore whether students perceive success in terms that are similar to how it is commonly operationalized. We also explored to what facets of student life students attribute their success or lack thereof. We interviewed groups of engineering students multiple times during their first year in university. Major findings include that students define success in a less stringent way than researchers do and students attribute their success largely to commitment to continue to spend time, to their motivation and their focus on goals that help the students focus their attention.

Introduction

Issues of student success, student retention and progress, are present in most universities of engineering and technology (e.g. Ohland et al., 2008). Delft University of Technology (DUT) is no exception. Over the past 50 years this university has attempted to increase the attainment rate and to reduce the time to graduation of its students. When we look at these indices for the past years, it is evident that these attempts have not been very successful: the first year drop out rate lies between 35 and 50 %, and the average time to graduation for a 5-year programme (bachelor and master) is 6.9 years. These numbers proved to be very hard to change. To understand why it is so difficult to influence student success the university commissioned a research project. It was decided to focus on the first year of engineering education only as a number of researchers determined that first year success is of paramount importance for persistence in engineering (e.g. Crissman & Upcraft, 2005).

Research questions

Student success is among the most widely researched areas in higher education. Researchers have studied the issue in many different contexts, testing different models covering a variety of variables. Outcomes of these studies are often ambiguous; variables have different effects in different contexts or sometimes no effect at all. In this project the first step is to develop a situated model of first year student success in DUT and the first step towards such a model is to establish how students perceive student success and what aspects of studying they believe contribute to their success. We pose the following research questions:
1. How do first year students perceive success in their studies?
2. Which elements of student life are perceived to be of importance for success by the students?

Findings from research into student success

As stated in the previous paragraph, much research has been done in this specific area of interest. Developments and major outcomes of this research can be found in e.g. Upcraft, Gardner and Barefoot (2005). For engineering student success specifically there is no synthesis of work done in the field so far, but over the past decade the number of rigorous studies in this field has grown considerably, e.g. Seymour & Hewitt (1997), Ohland et al. (2008) and Van der Hulst & Jansen (2002).

From this body of work a number of variables that are related to student success emerged. Student background variables including ability, age, gender, parental level of education and ethnicity were found to have effects on success, just like interpersonal interactions with fellow students and academic staff (Crissman & Upcraft, 2005). Institutional variables, e.g. curriculum organisation, also have effects. Van der Hulst and Jansen (2002) found that students in curricula with few parallel courses for which students are awarded a fair amount of credits are more successful than students in curricula with a large number of small courses.

Methods

The literature review yielded many different variables that are related to success. However, the aim of this research is to find out how first year students perceive success and to which aspects of student life they attribute their success. We decided to interview students several times during their first year. We chose to do focus group interviews using the storyline technique.

Focus groups and storylines

Krueger (1994) stated that focus groups can capture the dynamic nature of group interaction and create a social context that is more natural to respondents than individual interviews. It allows respondents to react to each other’s views and experiences and this generally generates a shared range of opinions that are present in the group. Extreme opinions are easier to detect, as respondents can bring up their experiences to contrast opinions they do not recognize.

In the first interview the students shared their first impressions. In the follow up interviews they were asked to look back at their experiences in the university by using a visual technique called ‘storylines’. This technique was first described and tested by Gergen (1988) A storyline is a two-dimensional graphic representation that shows a student’s experience on a time line (x-axis). Students were asked to think of those events that marked their experiences of the course of a semester and to indicate what effects these events had on their university experience (y-axis). This technique helps to gauge to what extent events were perceived positively or negatively by the students. Another
benefit of this technique is that it provides the students with a visual and something to do and focus on something other than the researcher. According to Gergen (1988) this technique makes it less confronting for respondents to discuss potentially sensitive topics.

**Sampling**

Students from Applied Physics (PH), Mechanical Engineering (ME), Aerospace Engineering (AE) and Policy Analysis (PA) were recruited in September 2009. Existing student mentor groups were approached for participation. These groups were assembled randomly by the programmes and a basic level of trust was already present in those groups, which was an advantage for focus groups. Participation in the interviews was voluntary. Students received a letter with information on the research and a consent form. Interviews were scheduled in breaks so they would not overlap with any education activities. Lunch was provided.

With the PA and PH students it turned out to be impossible to meet in the first semester. These groups participated in two interviews only. Not all the participants attended all the sessions, but all sessions were attended by at least three students. In this paper all names have been changed to ensure anonymity of participants. The substitute names of students in ME start with M, in PA names start with P, in AE with A and in PH with H. In this paper ‘programme’ refers to a curriculum and ‘course’ to a unit within a curriculum.

**Coding**

We transcribed all the interviews verbatim and analyzed the data using the Atlas TI software package. A codebook was created in an iterative process. First all transcripts were read carefully and coded using generic codes proposed by Miles and Huberman (2005, page 61). All transcripts were recoded using codes that referred to the setting the students related to. These ‘setting codes’ were based on the literature review and on a first reading of the transcripts. Next, all the categories were coded again using open coding. These open codes were revised and combined until there was a consistent set of codes. By using this diverging strategy we aimed to prevent bias through code development.

**Results**

We asked students about their success intentions for the first year and for later years in all three interviews. Success intention was taken as intention to pass all 60 credits of the first year in one year (this is referred to as P-in-1, between 10 and 35% of the students obtain 60 credits in their first year), how students perceived the reenrollment requirement of obtaining at least 30 credits in the first years and how they perceived drop out. Three general categories of success intention were identified.

1. P-in-1 as a beacon: Several students state that the P-in-1 is a beacon, a higher goal. They strive for it, but they do not find it a big deal if they do not make it. There are two lines of argumentation underneath: 1) It can’t be done anyway. Harald says that this believe that it cannot be done permeates all levels. At PH all students meet with academic staff members a number of times in the first year and Harald
felt this person tried to temper his ambition, although Harald passed all his courses with high grades. 2) Students do not know if this level of achievement is for them. Andrew says in the first interview he will start setting clear goals after the first round exams, not before.

2. P-in-1: so what!? Andrew states that he feels passing the test is less important than understanding the coursework. Matt is committed to becoming a mechanical engineer, but he prefers to take his time. If that means that he will take 6 years or slightly more, he is fine with that. The P-in-1 may still serve as a beacon for these students.

3. P-in-1: go for it! Some students feel that, since they need to pass these first year courses anyway, they prefer to get it over with. Some students have other motivations to want to pass the first year. For teaching assistantships and certain board positions a student needs to have obtained the first year diploma.

The students were asked for their aspirations regarding obtaining the bachelor diploma in three years. None of the students seemed to care. First they want to find out how they can be successful in university, pass the 30 credits reenrollment requirement and pass the first year.

From the open coding three other aspects of success emerged. These are described below.

- Feeling good about performance: Mary states that she has to make an effort to start preparing for the exams, but “it gives a kick when you look back when you passed all the exams after having given it your all.” Harald shares this feeling: he feels satisfied when he has worked hard and is rewarded with good grades. His peer group is very committed and there is competition for high grades. For Harald this is a source of motivation.

- Getting up after a fall: Hugo and Marc were confronted with not passing their exams. Hugo failed all of his exams in the first period of the year; Marc failed all but one in the second period. Both failed because they felt that the topics that were covered were very easy and they did not need to put in a lot of effort. Both managed to make up for this fall by working consistently hard during the next period and focusing all their attention and effort on achieving their goals. Hugo states that he felt ‘ecstatic’ when he found out that he had passed all his exams in the second period, even though he passed some with the minimal pass mark. Marc was set on passing as many courses he could and felt good about this.

- Having a rich student experience. Matt is most explicit about this, but Hannah and Mary mention it as well. They want more from student life than studying alone. They state that their side activities and the diversion help them keep up their motivation. Side activities can be very rewarding too and it is a great way to meet people outside the programme.

How do students perceive drop out? This question was pursued by asking students how they felt about friends dropping out of university and how they perceived the letter that informs them about their progress in the second education period.
Marcel states clearly in the first interview: “You don’t know if this is for you. You need to commit yourself and if you still fail, that is okay. You know you have given it your best and you can leave with your head held high.” Alex, Matt, Hannah and Howard state that they learned early on that many students drop out. They had heard this from fellow students, students at their fraternities or read it on the website. Hannah: “You just hear people talk about it, that 50% drop out in the first year so you take that as a fact.”

In follow up interviews students report different experiences. The PA students know that people drop out, they just do not know anyone who did and it puzzles them. They conclude that the dropouts are the people who never come to class. The students at ME lost some group members. One of them left right after the first round of exams, but he never bothered to inform the team and they needed about two weeks to find out. The students were surprised he left: they had not seen it coming. The students gone missing were replaced quickly, the project was unhurt and the students got over the incident quickly. The team at AE lost three students. The students talk negatively about one person. Alex says: “She quit at the beginning of the second educational period. She did nothing, she attended project meetings because it was mandatory, sitting there with her head down. ... She was no good at all.” Alice contends with this statement. The students who tried hard are talked about in a matter of fact way. At PH Hannah, Howard and Harald see students struggle, but it does not seem to affect them. Neither did the letter informing them about their progress.

The students who had been at risk at some point have different experiences. Malcolm admits in an interview that he is struggling and he found out that ME is not for him. He went to see the support officer but did not get the support he wanted. Prue had not passed many exams and received a letter in which was stated that she was at risk and she needed to work harder. She felt cheated, because she had tried hard but it just had not happened for her. For Hugo the letter was a real blow: having failed dramatically he felt bad enough already and he felt the letter informed him he was considered a basket case. The letter also served as a wake up call because it formally confronted Hugo with the fact he had passed none of his exams. Hugo is affected by the fact that some of his friends left the PH programme. In the third interview Hugo says he feels proud he recovered from his fall and that he will continue in PH. It seems to him as if there is a separation between students who do well and those who struggle, but this separation is hard to notice it as failure and struggle for success are not discussed openly. Harald disagrees and states that: “Everyone in PH likes the programme and is committed to their own success.” Harald thrives due to the competitiveness in PH as remarked earlier. Marc failed in the second period and he does not mention the letter, but he states that to him the failure felt like a blow and wake up call.

In conclusion of this section, it is observed that failure is not openly discussed among students. Dropping out is not talked about as something that is negative per se, but a lack of commitment is. The students who need support do not seem to get the support they would like. It is not something that seems to impact the students who stay, or possibly students decide not to waste time on it. All the other students talk about working hard and they attribute their success to their commitment to putting in effort.
The students were also asked which events influenced their experience as students and how. Five codes relevant to educational climate were identified: perceived quality of teachers, assessment and organisation of campus, curriculum and courses. These codes were explored using open coding and the open codes were revised and combined until there was a consistent set of codes. The number of instances that the open codes were used were counted and assessed on whether it was laden with a positive or negative value. A small number of topics score persistently negative: ‘curriculum organisation’, ‘quality of assessment’, ‘high course load’ and ‘fluctuations in course load’. ‘High course load’ and ‘fluctuations in load’ seem to contradict: student’s state that they spend long hours taking lectures and on independent study. When they also have lab and project work, they still need to attend lectures and keep up with their classwork and spend long hours working on practical work. The students in PH, AE and PA find it very difficult to combine these activities.

Most topics educational topics have mixed loads: some aspects are talked about in a negative way, other aspects of the same topic in a positive way. An example is ‘Teacher’s personal style’. Typical negative statements include: Teacher rushes class, does not listen to critique, is sarcastic, teacher is neither enthusing nor passionate, explains in an unstructured way. Typical positive statements are: Teacher appeals to and captivates students, is involved, shows passion for the subject, is authentic, takes students seriously, points out relevance of topics, structures and paces very well. Students surprisingly made contradicting remarks about the same course.

Besides codes that had to do with educational attributes, the students also mentioned a number of personal attributes that matter to their success. ‘Students’ social environment’ is mentioned 29 times. All aspects of social environment have mixed loads on the students. Fraternity membership is motivating, but is costs a lot of time too. Next to ‘student social environment’ most statements have to do with ‘time spent’ and ‘reflection’.

There are 25 statements on how students spend their time. Most of the students try to keep up with lectures and revise everything in the lecture free periods before the exams. Keeping this regime up requires a lot of discipline from most students. Planning is found to be important. Even Matt makes schedules for studying. He also plans time for his other activities. The amount of time students put in depends on how much time they have on their hands and on how important they feel it is to keep up with class work. If keeping up has served the student well, she will probably try to maintain this strategy. If keeping up has proven not to be necessary, a student will not change her ways until it goes wrong. The gap between secondary school and university is a part of this as most first year students are not used to working hard.

Most of the students cannot study all the time, at some point they need a break: they go on holidays, organize events, work out, do something to break routine. New courses and new approaches (practical work) help to renew/ maintain motivation and continue to work hard. Another source of distraction are fraternity, student association or activities that underline the opportunities in engineering. Examples are presentations of future employers or documentaries on Discovery Channel™.
Conclusions and reflections

The first research question is: How do students perceive success? Students see passing courses, and therefore progress, as ‘success’. Students also experience success when they achieve personal goals. These personal goals range from desire for deep learning to getting high marks to wanting to have a rich student experience with many side activities. A lack of success is a reason to give up for some students, for other students it creates the necessity and drive to achieve. Failing and dropping out seem to be viewed as facts of life, but not being committed to engineering is frowned upon.

The second question is: Which elements of student life are perceived to be of importance for success by the students? The most important elements are effort and discipline. Student related factors that influence success have to do with motivation to stick to a successful strategy and spending the time necessary to study for the tests. Every student develops a strategy that works, even if it creates pressure. Sometimes is works because it creates pressure. Most of the students report that they go to lectures regularly and pay close attention. There is consensus among the students that this regime is helpful for being successful. Even if students do not manage to keep up with class work, they have covered the materials by listening and making notes.

The consistently high course load is tough on the students. Alice, Alex and Andrew report fatigue, depression and other physical problems they attribute to the overloaded curriculum. Students in PH report on the fluctuations in study load: they spend long hours in the lab and during the weeks they have practicals, they feel there is no time to keep up with the work required for other courses. The PA students report that they feel they only have time to keep up with course work in periods with no projects scheduled. Other elements that influence student success have to do with the support of a peer group and with teachers’ personal style and didactical expertise. When teachers manage to appeal to students and create a fostering learning environment, this helps the students to put more effort into it. However, a teacher who is greatly appreciated by one student could induce resistance in another. The students do share experiences of didactical expertise. Teachers who structure their lecture well and who are enthusiastic about their topic are appealing to all students. These teachers usually have good course materials available that can be understood easily when the student has been to class. Students attribute most of their success to ‘working hard’. Talent, curriculum organisation and teacher quality have its’ effects, but according to the students success really comes down to the willingness to put in the necessary time and effort.

References


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Sharing the past, sharing the future, and sharing oneself in portfolio studios

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Abstract: Developing a professional portfolio through engagement in a portfolio studio offers students an opportunity to look at their past experiences in a new light, broadening their conception of what it means to prepare oneself for engineering. It also presents an opportunity to reframe and/or refine professional goals in the future. An outcome of shaping the past and future is further development of a professional identity, here described in terms of increased self-confidence in professional skills. In this mixed methods examination of students enrolled in portfolio studio, we analysed both interview and survey data to enhance our understanding of how students look to the past and the future, while also looking inward.

Introduction

For more than a decade, U.S. engineering education policy has included lifelong learning as an important professional competency (ABET, 1998-2009). Lifelong learning has been characterized in a variety of ways; in nearly all conceptions, time is a central feature. Whether they are learning from the past in a process of critical reflection (Brookfield, 1995) or preparing for the future by engaging in an on-going process of self-managing, self-monitoring and self-modifying their learning (Candy, 1991), lifelong learners never situate their learning solely in the present moment, but rather situate their learning in their histories and/or visions for the future.

A portfolio is one intervention that can develop lifelong learning skills in engineering students. Riley and Claris (2008) write, “Portfolios can be an important way to incorporate lifelong learning skills, because, when implemented well, they embed self-directed learning skills such as articulating learning objectives, assessing how and to what extent those objectives have been met, and reflecting on how to improve targeted skills in the future.” A portfolio may be characterized as a purposeful compilation of one’s work, typically in service of an implicit argument. Our implementation of the portfolio consists of a professional statement in which the student makes claims about her preparation for an
engineering profession, provides artifacts from prior experiences, and includes annotations explaining how the artifacts support the student’s claims in the professional statement (Turns, Cuddihy, & Guan, 2010; Turns, Sattler, Eliot, Kilgore, & Mobrand, In press; Turns, Sattler, & Kilgore, 2010).

Students develop their professional portfolios via engagement in the “portfolio studio.” Grounded in social constructivist theory (Vygotsky, 1978) and situated learning (Lave & Wenger, 1991), the studio approach to portfolio development consists of a series of organized and facilitated group sessions in which students share and peer review their professional portfolios as each unfolds over time, in a studio environment (Sattler, Kilgore, & Turns, 2010; Sattler, Thompson, Turns, & Kilgore, Forthcoming).

In contrast to many portfolio implementations for assessment purposes (see, e.g., Baume & Yorke, 2002; Gibbings & Brodie, 2008; Johnson, 2006; Johnston, 2004), we prioritize learning and development. Our approach to portfolio is distinguished by three qualities. First, the instructor does not declare expectations for what is to be included in the student’s portfolio and does not evaluate the quality of the portfolios. Rather, the instructor directs students to make their own decisions and evaluations in collaboration with one another. Second, we ask students to choose their audience for the portfolio; often they select prospective employers. Finally, our approach is distinctive in that it involves extensive sharing and peer review of the portfolios themselves as they are being developed over time, rather than of the work products that go into them. To enable students to make significant progress on a professional portfolio in one academic quarter, studios are organized around “liberating constraints” that guide rather than prescribe (Davis, Sumara, & Luce-Kapler, 2000).

In a study of 11 students who participated in portfolio studio in 2009, we argued that through the process of reflecting on experience for the purpose of gauging their own preparedness for engineering, students added educative value to those experiences (Kilgore, Sattler, & Turns, In Press). In the present study, we extend our understanding of students’ reflections related to participation in portfolio studio to include both the past and the future. We also explore the role that such reflections can play in professional identity development.

Our research questions are:

1. Do students shape the past and the future through engagement in portfolio studio and development of a professional portfolio?
2. What are the implications for the development of self as engineer?

Research Methods

Sample

In the Winter Quarter of 2010, 44 students enrolled in one of three sections of a one-credit portfolio studio. All entering students filled out a pre-instructional survey that included questions designed to elicit their perspectives on engineering, portfolio, and themselves as
engineers. At the conclusion of the quarter, 29 students filled out a similar post-instructional survey. Of those, 23 consented to include their course materials in this study and 12 of those agreed to participate in further research efforts. These 12 students responded to an open-ended questionnaire directed toward eliciting recollections of their reflective processes while engaged in portfolio studio. Of the 12 who filled out the questionnaire, 5 participated further in a one-hour open-ended interview.

Figure 1: Portfolio studio and research participants. The arrows represent that students in each subsequent phase of the study were drawn from the sample in a previous phase.

We were unable to target underrepresented minorities in engineering in this study, and the sample was not diverse in terms of race/ethnicity or gender. Of the 44 initially enrolled, 34 were men and 10 were women. Of the 44 initially enrolled, 19 were Asian or Asian-American, 22 were white, 1 was Hawaiian/Pacific Islander, and 1 was Hispanic (one did not report). Of the 12 research participants, 11 were men and all were either white or Asian/Asian-American. The sample was diverse in terms of major with 10 engineering subdisciplines represented. The sample was also diverse in terms of pathway to university; 16 of the 44 initially enrolled were transfers from 2-year colleges. Students were mostly juniors and seniors.

Data analysis

The targeted research survey asked students to reflect on their experiences developing a portfolio and participating in portfolio studio, and to discuss what it means to be prepared to be an engineer. With the help of Atlas.ti, we identified emergent themes arising from students’ written answers. During a first coding pass of the data, one of our goals was to identify narratives that addressed reclaiming experience and the interplay of goal setting and portfolio development, as discussed in prior studies. We also coded for identity in this first pass, as this category emerged from the data as well. A second coding pass involved a closer examination of how students were discussing their interaction with and reflection upon their pasts and futures, as well as the links between these activities and identity development. We then invited five of the students to participate in in-depth interviews. For each of these participants, we developed a comprehensive profile of what we already knew about the student based on their responses to the pre- and post-instructional surveys and the research survey, and developed questions to further explore the themes—past, future, and identity—emerging from the analysis of survey responses. This iterative process is characteristic of a grounded theory qualitative research approach (Glaser, 1992).

Supporting quantitative data were analyzed using SPSS. In particular, we examined students’ reported self-confidence at the beginning and at the conclusion of the quarter.
the beginning and end of the quarter, students were asked to rate themselves as compared to their peers on the following competencies: self confidence (social), leadership ability, public speaking ability, math ability, science ability, communication skills, ability to apply math and science to real world problems, business ability and ability to perform on teams. A 5-point Likert scale was used for self-reporting: Highest 10%, Above average, Average, Below average, and Lowest 10%. Students’ responses were rank-ordered for purposes of analysis. Two constructs were calculated, organizing students’ answers into one of two categories: technical or professional skills. A summary self-rating for technical skills was calculated as the mean of ranks for math ability, science ability and ability to apply math and science to real world problems. A summary self-rating for professional skills was calculated as the mean of ranks for self-confidence (social), leadership ability, public speaking ability, communication skills, business ability, and ability to perform on teams. The Wilcoxon signed rank test was used to compare pre- and post- computed technical skills ratings and professional skills ratings.

Findings

Shaping the Past

We began our analysis with the qualitative data gathered from open-ended survey and interview questions. A first coding pass confirmed previous research findings. Of the 12 students in the study, 10 described that the experience of portfolio studio and developing a professional portfolio resulted for them in a new way of looking at and conceptualizing their past experiences. In particular, students reported that they found value in experiences they had not previously thought valuable, and that they had gained a greater appreciation for their past accomplishments. For example, Brian had been on a mission trip to Juarez, and said of his mission trip to Juarez to build houses, “I had always thought of this experience as a cool thing that I got to do...but through the portfolio, I linked the house-building to engineering.” Jin-Ho had been “fiddling with modeling clay for most of my life.” He added, “[A]fter reflecting on it, I realized that I have been thinking like an engineer about even something as seemingly non-engineering related as that.” In addition to these specific experiences, students like Christopher described their newfound accomplishments more generally, “It was very rewarding in the end to see how much work I actually had done in my past.” For Christopher, it was “eye opening.” He added, “It is amazing to look back at the past with the portfolio in mind and see how many experiences are applicable.” Jin-Ho said of these discoveries, “It's like digging up your closet and finding a 50 dollar bill in your old jacket that you haven't used in a few years.”

Shaping the Future

In addition to reframing their past experiences, to a lesser extent students reframed their future goals. Nine of the 12 students described adjusting their short-term goals in light of needs they identified after reflecting on their experiences. For some of these students, this meant identifying specific actions they intended to take, like getting an internship or research experience. Jake said, “[A]fter looking at the work I have done, I feel that there need to be more research/projects within my field, of which I have not done so much.”
Shing also felt, “I should and need to get an internship as soon as possible.” Other students said they planned to approach new experiences more intentionally. For instance, Matthew said he now “tends to think back on prior experiences to relate and add to my portfolio.”

Just two of the 12 students described an adjustment to their long-term goals in light of their increased knowledge about themselves. For example, as an aspiring designer, Tyler “took every experience and related it to the concept of design” while developing his portfolio. “I made sure it reflected my love of design, a personal trait upon which I wish to capitalize.” At the time, Tyler was deciding whether to apply to the departments of Civil Engineering or Human Centered Design and Engineering. “Ultimately, my love of design won out.” In focusing his portfolio on design, “I was able to affirm my plans to pursue a degree in Human Centered Design.”

Shaping the Self

In shaping their past and their future, many students also engaged in shaping themselves. Seven of the 12 students described an increased sense of confidence and/or self-efficacy as a by-product of reflecting on their experiences. Jonathan described how in gaining an increased sense of accomplishment, “you really discover what makes you tick, what you can be proud of, and why you want to do engineering.” Cole explained, “I came to realize how much I was already prepared to be a professional engineer after taking this course. Before that, I felt like I was still „just a student.”” Jin-Ho also “felt better about myself and became more confident about my past.”

Students enrolled in the portfolio studio had a healthy regard for their skills and knowledge to begin with. At the beginning of the quarter, students were asked to rate themselves as compared to their peers on the following competencies: self confidence (social), leadership ability, public speaking ability, math ability, science ability, communication skills, ability to apply math and science to real world problems, business ability and ability to perform on teams. A 5-point scale was used for self-reporting: Highest 10%, Above average, Average, Below average, and Lowest 10%. A majority of students rated themselves as average to above average in each of the categories.

At the end of the quarter, students were asked to rate themselves again. Their self-confidence in the technical competencies – math, science, and ability to apply math and science to real world problems – was consistent with prior ratings. On the other hand, students were significantly more likely to assign higher ratings to themselves in professional skills like leadership ability and communications skills (p<.002). This may have been an outcome of having successfully employed those skills in developing the portfolio and participating in portfolio studio. Students also indicated that increased clarity with respect to accomplishments caused them to think more highly of themselves. Matthew described the novelty of the process, “I had to think a lot more about the positive aspects myself, which is something I usually do not do, I have to admit.” Jonathan described how in making links between experience and engineering, “in that way, I guess it changes your perception of yourself as an engineer.”
Discussion

In a prior study, we observed that portfolio studio affected how students understood their past experiences, as revealed by analysis of interview data gathered from 11 engineering students who participated in portfolio studio for an academic year (three quarters) (Kilgore et al., In Press). In a separate case study of two of those students, we observed that portfolio studio also affected how they understood their goals for the future (Sattler et al., Forthcoming). The present study affirms and extends these works by combining reflection on past experience and future goals into a more comprehensive model of sense-making and identity development in the portfolio studio, as illustrated in Figure 1.

![Figure 1. Shaping the past, the future, and the self in portfolio studio.](image)

Many students have told us that development of a professional portfolio in studio enables them to make new sense of past experiences in the following ways: (1) they gain better appreciation for the value of any and all experiences they reflect on, (2) they are able to better and more explicitly make sense of how any experience upon which they reflect contributes to their preparation to be engineers, and (3) they become more aware of the gaps in their experience and what they must do to fill those gaps. In this paper, "shaping the past" describes this process of re-framing past experiences.

At the same time that portfolio studio requires students to reflect on their experiences, it also necessitates that students explicitly express and employ their professional goals as a frame for making sense of the tasks involved in constructing the portfolio. Students have told us that the development of a portfolio enables them to make new sense of their goals. Most commonly, students identify and refine short-term goals and strategies to close the distance between their preparedness and their long-term professional goals. Occasionally, students adjust long-term goals in light of new sense they have made about themselves as

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a result of reflection on their past experiences. “Shaping the future” describes this process of re-framing future goals.

Identity development can be a by-product of these reframing activities. In this paper, we described how some students appeared to develop greater self-confidence while at the same time a more comprehensive and balanced understanding of their learning needs emerges. The processes of shaping the past in portfolio studio and through development of a professional portfolio often result in a greater sense of accomplishment with respect to engineering preparedness and an increase in self-confidence. The processes of shaping the future in portfolio studio and through development of a professional portfolio often result in a much clearer assessment of what remains to be learned and developed to ready oneself for an engineering career. In other words, students gain greater appreciation of themselves as engineers while at the same time gaining a more explicit sense of where they still come up short with respect to their professional goals. “Shaping the self” describes this ongoing process of increasing self-confidence.

Implications

The people whom we call engineering students are not coherent, unified selves, though there is every indication that engineering educators make this assumption. Students can hold multiple perspectives stemming from their varied backgrounds, as children in families; as members of a particular race or ethnicity, social class, gender, sexual orientation; as workers, volunteers, lovers, or enthusiasts (Kilgore, 2004). In engineering education, as in most majors, students’ multiple selves are ignored in favor of the individual whose sole purpose is to logically progress toward some educated endpoint. Engineering students often are very clear about what they consider engineering knowledge and what they do not. This notion is introduced and reinforced structurally, institutionally, and pedagogically. Portfolio studio is a first step for many students to explore and recognize the inherent value of their other selves from within the context of engineering education. It also provides an opening to challenge that which is taken-for-granted in engineering education from these other perspectives.

One potential critique of the development of a professional portfolio in portfolio studio is that it is a means to “manage” students’ understandings of their experiences in service to the traditional ideals of engineering education. Political, social, and cultural forces shape our understanding of what is appropriately reflected upon, what is appropriately learned from it, and to what ends experiences are employed (Fenwick, 2001). Though we leave the definition up to the students in collaboration with each other, it is true that conceptions of what it means to be prepared for engineering are strongly formed within the political, social and cultural context of engineering education. At the same time, by encouraging students to survey and share experiences well beyond the engineering classroom, there is the possibility of resistance to and reconstruction of the traditional notion of engineer through the multiple lenses brought by the many individuals to the studio.

Professional portfolio development is relatively inexpensive and easy to implement in university programs. Although it would be nice if there were large scale institutional
reform to accommodate today”s global technology-driven workplace context while also opening a space for students to explore and acknowledge their multiple selves, it may not be practical to rely on that any time soon. Existing courses and major requirements do not have to change for students to do identity work through the construction of a professional portfolio. More importantly, there may be potential for students to develop those elusive lifelong learning competencies that are oft-discussed by engineering leaders but rarely addressed in engineering classrooms today.

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Engineering Student’s Conceptions of Model Uses in Design

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Abstract: The engineering curriculum is steeped with instances of modelling use, especially in design applications. The implicit inclusion of modelling in the typical engineering curriculum often results in conceptions of models as being primarily used for visualization and testing, originating from the descriptive nature of everyday use. A broader understanding of how models are used can be achieved when students are given opportunities to learn and experiment with the predictive nature of some modelling applications. A significant shift in conceptions was observed between pre and postsurveys of senior engineering students taught an explicit modelling intervention. Visualization and testing remained prevalent with an additional focus on predictive mathematical models.

Introduction

Many courses in an engineering curriculum focus on teaching students engineering fundamentals. Engineering fundamentals can include many different disciplinary topics, but one underlying emphasis is to develop analytic skills that are rooted in basic mathematical and scientific principles. Typical engineering courses engage students in deriving, using, and applying theories, equations, and models in a variety of problem solving contexts. Yet, the implicit nature in which these skills are taught often conceals important features of modeling fluency that are necessary for students to develop a full understanding of the content.

Our research investigates the use of models and modeling during engineering design. Student conceptions of models were shown to be heavily focused on physical representations (e.g. prototypes, mock-ups, drawings, and sketches) (Carberry, McKenna, Cole, & Linsenmeier, 2011; McKenna & Carberry, 2011). Physical-centric conceptions tag models as describing what is expected, but overlook the predictive power of models to represent theoretical behaviors (Starfield, Smith, & Bleloch, 1994). The versatility of models and their ability to be both descriptive and predictive are important to learn in engineering. The following research expands on what we know about student conceptions of modeling to explore their ideas of associated uses. We therefore ask the following question: ‘In what ways do students believe models can be useful/helpful in the design process?’
Theoretical Framework

We frame our study using the adaptive expertise model. According to Schwartz, Bransford, and Sears (2005), an adaptive expert is someone who not only has deep subject matter knowledge, but also can recognize when this knowledge applies in a novel setting. Our study analyzes adaptive expertise as it applies to how one flexibly uses knowledge of modeling. Modeling know-how falls under the banner of “computational adaptive expertise” or CADEX, which concentrates on the development of analytical and computational knowledge (McKenna, Linsenmeier, & Glucksberg, 2008). Many engineering courses teach these topics without explicitly acknowledging how analytical techniques serve as representations of a physical phenomenon. This approach omits an important step in the development of a robust fluency.

Modeling Literature Review

Given the pervasiveness of modeling in engineering, our current paper explores students’ conceptions connected to the use of modeling. The teaching and learning of modeling is easily complicated by semantics in that the term “model” can be a noun, verb, or adjective. Maki & Thompson (2006) note that the term modeling has different meanings depending on the context. In everyday use, modeling references a display version or miniaturization of something. This use of the term corresponds in engineering to physical models intended for experimentation, display, and emulation purposes. Engineers also use the term model to describe theoretical, logical, and mathematical representations which represent behaviors (Starfield et al., 1994). The everyday use of the term is often not consistent with the nuanced technical meaning.

A goal for teaching modeling is therefore to guide students in the discovery of the intended uses, appropriate applications, and embedded assumptions of models. Modeling in engineering is a process not just a product. As Lesh & Doerr (2003) describe, modeling is a cyclic activity consisting of real world descriptions, prediction manipulation, and verification. Modeling as a process provides students with an understanding of how to create purposeful and meaningful representations.

Perkins (1986) cautions that the term model does not include everything. Models are intrinsically ambiguous, and often additional information is necessary to make sense of any model. Models are typically taught using the general method of highlighting features with words or labels. This can lead to a compound effect of using one type of model (e.g. words and symbols) to explicate or highlight aspects of another model (e.g. sketches and diagrams). As educators we take for granted that students understand that we are teaching different types of modeling that are appropriate for different types of analysis and decision-making. The explicit reasons for modeling fade in the background such that they become invisible causing students to often lose sight of or not even notice that they are engaging in the process of modeling, and for what purpose.

In engineering education, research on embedded modeling interventions has come by way of modeleliciting activities (MEAs) (Deifes-Dux, Moore, Zawojewski, Imbrie, & Follman,
2004; Diefes-Dux et al., 2004; Moore & Diefes-Dux, 2004; Yildirim, Shuman, & Besterfield-Sacre, 2010). The use of MEAs is intended to promote problem solving and student thought processes by encouraging students’ use of mathematical models during engineering tasks. In addition, the research team associated with this project has conducted multiple studies using an explicit mathematical modeling intervention to improve students’ design ideas and solutions (Cole, Linsenmeier, McKenna, & Glucksberg, 2010; Cole, Linsenmeier, Molina, Glucksberg, & McKenna, 2011).

Research Methods

Our study investigated the impact of an explicit modeling intervention on conceptions of modeling uses for 48 senior biomedical engineering students. The modeling intervention (Cole et al., 2011) consisted of a series of modeling tasks that mapped to the mathematical modeling process described by Gainsburg (2006):

1. identify the real-world phenomenon
2. simplify or idealize the phenomenon
3. express the idealized phenomenon mathematically
4. perform the mathematical manipulations
5. interpret the mathematical solution in real-world terms
6. test the interpretation against reality.

The intervention was implemented as part of the course material in conjunction with the students’ senior capstone design work. The tasks focused on the design of a phototherapy device used to treat neonatal jaundice. Students were instructed over the course of the intervention to advise a hypothetical design team. The general pedagogical approach taken with the activities was to allow the students to attempt the activities followed by a discussion/lecture about the ideal processes. Student conceptions of modeling uses were recorded at the beginning of the course prior to any instruction and again approximately one month after the end of the intervention, prior to the start of the new term.

Data Analysis

An open-coding approach was taken to identify emergent categories in the data. A single rater first read each student’s response to determine a set of categories compiled into a rubric. The rubric was then used to code each student’s response. A second rater subsequently used the rubric to test its validity. The second rater repeated a two-step process consisting of 1) coding 10% of the responses using the rubric, and 2) consulting the first rater’s codes, until agreement was reached. Changes to the rubric were made to establish 100 percent inter-rater reliability between the two raters. In its current state, the rubric consists of twenty-three codes (Table 1).

For organizational purposes we have grouped the codes into the following five categories: description and display, development, prediction, project management, and testing and evaluation. These categories represent several design process activities and serve as a shorthand way to group the data for discussion purposes.
Results & Discussion

A large number of codes emerged from the student pre and post data. At this preliminary stage of our study, we decided to be prudent and retain all codes in an effort to not overlook codes that may prove in the future to provide valuable insight into students’ uses of models. Figure 1 displays the pre and post results. Pre-survey results identified feasibility as the most sited use of models. Over twenty percent of students also sited visualization, understanding the solution, improvement, and testing performance. After the modeling intervention, student conceptions cited feasibility, visualization, understanding the solution, and improvement less. Testing performance increased, while cost consideration, time management, and prediction became pertinent. None of the remaining categories were cited more than 17% for either the pre or post survey.
A paired-samples t-test was conducted to compare pre and post-intervention responses. A significant difference in the number of students between pre and post-surveys was observed for cost considerations, improvement, optimization, prediction, time management, and understanding the solution as uses for models (Table 2). Of the six significant categories, only improvement and understanding the solution went down from pre to post (as indicated by the positive t-value). The remaining categories were consistently cited between pre and post-survey.

A significant shift was observed for students identifying models as used for optimization and prediction when an explicit modeling intervention was introduced to these students. Even with the increase in identifying the predictive capabilities of modeling, students’ identification of models as used for visualization, testing, and feasibility assessment did not significantly depreciate suggesting maintained conceptions. The increase in cost consideration and time management is likely associated with the class instruction related to money and time saved though mathematical modeling.

Our findings suggest that the visualization and testing focus of model use is a product of not only semantics, but also course experiences. When modeling is made explicit to students, as it was in the described intervention (Cole et al., 2011), they appear to grasp
the great number of uses for models in engineering design. By making modeling steps more explicit it helps students to recognize the value of the predictive nature of modeling, and leads to changes in what is conceived as modeling. As we continue this research, we aim to shed light on how to effectively teach modeling, so that the implicit activities of modeling, i.e. the process, are given as much attention as the tools or products of modeling thereby helping students to develop more sophisticated conceptions of a core engineering skill.

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Note: *p ≤ 0.05; **p ≤ 0.01; ***p ≤ 0.001

Table 2: t-values for codes with significant changes between pre and post-survey

Conclusions, Implications, & Future Work

Modeling is an important part of engineering and the design process. Our initial findings suggest that students often do not have very nuanced conceptions of the full power and use of models in the context of a senior design course. We have indicated that students describe multiple ways to use models in a design solution and that most students view models as a means to visualize and test their solutions. However, when presented with an activity that explicitly embeds detailed steps of mathematically modeling in the context of design, student responses include increased mention of the predictive power of modeling.

While our work has provided useful insights, additional studies are needed to further investigate the modeling conceptions of engineering students at all levels in all disciplines. This type of crossdisciplinary and multiple year data can inform how modeling might be taught throughout the engineering curriculum.

Explication of modeling depends highly on the current curriculum used at a given institution. In some instances the changes may simply be for analysis-focused courses to be more explicit about how modeling is used in the context of setting up a problem and deriving a solution. Other situations may call for a necessary embedding of modeling as a core component of design-focused courses. Changes in the way modeling is taught can improve the way that students perceive modeling and increase their modeling expertise.
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Abstract: As the discipline of engineering education is currently in the process of developing its own research paradigm, the engineering education community takes considerable interest in development of the philosophy of engineering with an appreciation of the nature and role of engineering. However, this was achieved without a coherent model to guide the study of engineering-specific growth of beliefs. The authors used theoretical literature in educational psychology and conceptual and empirical work from engineering education literature to support the development of such a model. We adopted three dimensions as our analytical framework: a transdisciplinary view of engineering epistemology, beliefs about engineering knowledge and knowing, and beliefs about the nature of engineering reality, in order to establish a more comprehensive philosophical exploration. This effort may provide a fruitful line of inquiry for researchers and for those teaching in engineering disciplinary areas.

Introduction

High impact innovations for “engaging future engineers” necessitate research (Adams et al., 2011). In a landmark series of colloquia, a community of engineering education researchers defined five research areas for the emerging discipline of engineering education research (EER), including “engineering epistemologies” (The National Engineering Education Research Colloquies, 2006). The area of engineering epistemologies was conceptualized as “research on what constitutes engineering thinking and knowledge within social contexts now and into the future” (p.259). The emergence of interpretive research paradigms has led more researchers contribute to a better understanding of the benefits of and the need for epistemological diversity in an engineering setting (Douglas et al., 2010). This is particularly important for assessment of the development of engineering thinking and to measure transfer of what is learned into the practice.

This paper presents the development and validation of an instrument to assess Engineering-specific belief systems: epistemological beliefs, epistemic beliefs and ontological beliefs (see Figure 1). We identified common beliefs about the nature of engineering as a specific discipline (epistemic), as well as those beliefs, which are more particular to the nature and role of knowledge (epistemological) and the nature and role of reality (ontological) in the research and practice within engineering. To achieve this task, we propose to extend the existing terminology of “epistemologies” by adding
epistemic beliefs and ontological beliefs to differentiate nuances in the described phenomenon.

Definitions

The introduction of new terminology requires initial definitions: **Ontology** is the study of the nature of reality (Hofweber, 2004 in context of philosophical discourse; Lincoln & Guba, 2000 in context of empirical research). Philosophers of science have traditionally distinguished between epistemological beliefs from ontological beliefs and/or worldviews and have then claimed that both contribute to the way that scientists will necessarily view, conduct research, and construe theories of science and meta-science (e.g. Kuhn, 1962). We have added the new category of ontological beliefs describing the role that one’s beliefs about the external world of nature plays in one’s knowledge of the discipline or in one’s belief about how we know what we know. As James (2005) suggested ontology and epistemology are interconnected. A developed understanding and appreciation of both ontology and epistemology are expected to disclose philosophical divergences and, thus, can foster reflexive thinking by encouraging students to confront and justify their own ideas, beliefs, and positions.

![Proposed Model of Epistemological Beliefs](image)

**Figure 1: Proposed Model of Epistemological Beliefs**

**Epistemic Beliefs** are defined as the beliefs on the nature of epistemic frames (Shaffer, 2006) or the knowledge that, knowing how and knowing with contextualized within a discipline or place of practice. Epistemic frames are to know whom to ask, where to begin looking, what constitutes appropriate and accepted evidence and when to draw a conclusion (see Shaffer, 2006, p.227). We chose to include epistemic beliefs in this model to acknowledge that epistemological and ontological beliefs cannot be separated about the beliefs of what are acceptable standards and practices in the context in which they are employed aka the disciplinary boundaries.

**Significance of this work**

Previous research has focused nearly exclusively on epistemological beliefs, therefore, the authors of this paper presume that epistemic beliefs, ontological beliefs and
epistemological beliefs are inextricably linked and influence each other and thus added newly developed dimensions about epistemic and ontological beliefs to the instrument to assess their joint contribution (Schraw & Olafson, 2002). In terms of the broader engineering beliefs, this paper thus attempts to examine a more encompassing picture by examining a coherent model for the transdisciplinary epistemology of engineering (Figueiredo, 2008; Lipton, 2010).

The implications for engineering education research are twofold. First, this paper shall propose an alternative framework for the design of assessment techniques that unravel the relationships between the distinct kinds of beliefs present in the discipline of engineering, and this framework will provide a good baseline for the needed continued research that will seek for a better validated operationalization of engineering related beliefs. Second, the exploration of philosophical perspectives, in part the main epistemic, ontological and epistemological beliefs, should lead to a differentiated view of intellectual maturity and will hopefully provide direction regarding appropriate interventions for the education of engineers.

**Theoretical Framework**

To capture a more encompassing picture of the engineering-specific epistemologies (the broader term as defined by the research colloquia), we have expanded the range of approaches to the view about the field of epistemology as a discipline as well as the study of discipline specific knowledge and knowing (epistemic) (Kitchener, 2002). For this purpose, the authors investigated a coherent transdisciplinary frame of engineering that continually appeared in the literature, known as the domain-specific influences on beliefs about engineering knowledge and practice. Epistemological beliefs are empirical objects of psychological inquiry in which 'belief' can be pre-defined based on formal epistemology in a certain domain. For this purpose, we developed items of engineering knowledge and knowing based on Hofer's four dimensions of domain-specific epistemological beliefs (2002). With respect to ontological beliefs, we have initially adopted two opposing positions, as a traditional approach: Realism and Idealism, and have then gone on to add an ontologically neutral position based on the perspective of pragmatism. Although there has been much criticism on this type of unifold approach for an ontological worldview (Hammer & Elby, 2002), we cannot deny the fact that the “unitarity” has played a critical role in studies of philosophical perspectives for further deliberate investigations toward manifold ontology, epistemology, and methodology. Therefore, considering the developmental nature of our ongoing research, the current paper has applied the “unitarity” into the item development of ontological beliefs.

**View of Discipline: Trans-disciplinary Views of Engineering Beliefs (Epistemic)**

As noted earlier, recent years have seen an increasing discussion about engineering epistemologies; With regard to the role of the humanities in engineering, a number of studies on the differences and similarities between science and engineering have centered on the investigation of the nature of engineering epistemology (e.g. Adams, 2004;
Bucciarelli, 2003; Dym, 1994; Dym et al., 2005; Koen, 2003; Wulf, 2002). Karatas (2009) conducted a thorough literature review to summarize the main tenets of the nature of engineering and then went on to suggest that the characteristics of engineering solutions are tentative; theory and failure laden; socially and culturally embedded; and, finally, require creativity, imagination, integration, and a holistic approach for goal-oriented design. Carberry (2010) developed the Epistemological Beliefs Assessment for Engineering (EBAE) that is the first and latest quantitative instrument to assess epistemological beliefs (in the broader sense) in engineering. This instrument has several limitations: As noted by Carberry, the main factors of general epistemological beliefs instruments were adapted as template, in this case the Epistemological Beliefs assessment for Physical Science (White et al., 1999) supplied the main base for the EBAE. In fact, only two items directly related to engineering epistemology: one is about the differentiation of engineering from science; the other is about the importance of design in engineering. More importantly, most items were related to beliefs about engineering learning.

Figueiredo (2008, 2011) suggested a more coherent transdisciplinary epistemology of engineering is not limited to the comparison between engineering and science. He proposed a four dimensional epistemology of engineering: basic sciences, human sciences, design, and crafts. The basic sciences view of engineering as an applied science and mathematics is based on the predominantly analytical and positivist epistemology in engineering, whereas the human sciences carry an intrinsically interdisciplinary, interpretive, and integrative tradition in engineering (Radcliffe, 2006). The epistemology of the crafts is supported by the traditions of pragmatist philosophers (Schön, 1983), while design is becoming more widely considered to be the central or distinguishing activity of engineering, as a systematic and intelligent process (Dym et al., 2005). Accordingly, we adopted this framework, anticipating that this study would show how the aggregation of these four dimensions of engineering in a relationship of transdisciplinarity have considerable conflicts in values, methodologies, and goals.

![Figure 2: Figueiredo, Four dimensions of engineering (London: UK, 2008), quoted from Adams et al., Multiple Perspectives on Engaging Future Engineers (Journal of Engineering Education, 2011) p.66](image-url)
On the basis of these four dimensions, we developed a 16-item scale for epistemic beliefs (Table 1). Because engineering as defined here represents a transdisciplinary epistemology, the scale assesses the respondents’ self-reported beliefs of engineering as a discipline.

Table 1: Items of Transdisciplinary Views of Engineering Epistemology (Epistemic Beliefs)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Sciences</td>
<td>Engineering is a problem-solving activity within the context of society and culture. Engineers are not only technical experts, but also social experts, managers, and business people. Engineering activities are always contain value. There is no clear, right answer for engineering problems.</td>
</tr>
<tr>
<td>Basic Sciences</td>
<td>Science and engineering are complementing each other. Science and mathematics serve as the language of engineering. Engineering searches for and theorizes about processes (e.g. control and optimization) rather than causes (e.g. gravity, electromagnetism). Engineering is rather engaged in improving processes than discovering new knowledge (or solving mysteries). Engineering is the application of science and mathematics within a problem solving context.</td>
</tr>
<tr>
<td>Design</td>
<td>Engineering design values systems thinking more than analytical thinking. Engineering design allows human beings to form and transform nature with the aid of tools and procedures. Engineering design requires creativity and imagination to solve engineering problems. Engineering design requires a holistic and integrated perspective on reality.</td>
</tr>
<tr>
<td>Crafts</td>
<td>Engineering is about designing artifacts and systems to change the world and/or overcome resistance and ambiguity. Engineers need to be trained in technically expert craftsmanship. Engineering artifacts can be viewed as entities (objects) developed by a step-by-step procedure. Engineering artifacts result from good decisions based on the integration of many competing demands, theories, and ideas.</td>
</tr>
</tbody>
</table>

Epistemological Beliefs: Beliefs about Engineering Knowledge and Knowing

Since we agree with Hofer and Pintrich's (1997) argument that beliefs about learning need to be distinguished conceptually from beliefs about how we know what we know, we have adopted their four basic categories of epistemological beliefs, namely: certainty of knowledge, simplicity of knowledge, sources of knowledge, and justification of knowing. To develop items related to engineering knowledge and knowing, we adopted Hofer’s discipline-focused epistemological beliefs questionnaire (2000) as well as Carberry’s the Epistemological Beliefs Assessment for Engineering (2010). As noted earlier, we excluded items related to beliefs about engineering learning in order to conceptually distinguish said items from beliefs about engineering knowledge and knowing. As a result, Table 2 shows the 16 items related to beliefs about engineering knowledge and knowing.
Table 2: Items of Beliefs about Engineering Knowledge and Knowing

| Certainty of Engineering Knowledge: Knowledge is viewed as absolute or contextual. |
|---|---|
| Principles in engineering are unchanging so that they cannot be argued or changed. |
| All engineering experts understand engineering problems in the same way. |
| Most engineering problems have only one right answer. |
| Engineers should simply gather information, understand the ‘big ideas’, and develop new theories. |

| Simplicity of Engineering Knowledge: Knowledge is viewed as an accumulation of facts or as highly interrelated concepts. |
|---|---|
| Engineering knowledge is an accumulation of facts. |
| Engineers can solve engineering problems by just following a step-by-step procedure. |
| Engineering knowledge includes the isolation and definition of distinct concepts. |
| All engineering experts make more or less value-free statements. |

| Source of Engineering Knowledge: Knowledge is handed down by external authority or constructed by individuals. |
|---|---|
| New engineering knowledge is produced as a result of discovery (mainly by controlled experimentation). |
| Engineering knowledge should be accepted as an unquestionable truth. |
| Engineering knowledge is created only from an expert’s logical thinking. |
| There is one universal engineering method. |

| Justification for Engineering Knowledge: Individuals move through a continuum of dualistic beliefs to the multiple acceptance of opinions to reasoned justification. |
|---|---|
| Engineers can solve engineering problems by following a step-by-step design procedure. |
| First-hand experience is the best way of knowing something in engineering. |
| We can develop engineering knowledge, whenever an engineering expert transmits his or her knowledge to us. |
| Understanding engineering principles written by experts is equivalent to getting the right solution for engineering problems. |

Ontological Beliefs: Beliefs about the Nature of Engineering Reality

Ontological beliefs are defined as beliefs about the nature of reality. Several studies have examined ontological beliefs using qualitative methods, such as think-alouds, interview techniques, and content analysis of verbal explanations (Slotta & Chi, 2006, Gupta et al., 2010; Hammer et al., 2011). In this paper, we begin with the definition of ontological beliefs by assuming that each type of belief exists on a continuum that ranges from realist to relativist endpoints. Realism refers to the fact that entities or phenomena (e.g. knowledge) exist and can be understood and explained to some degree, even though experts do not understand that phenomenon. Idealism asserts that entities may exist in an everchanging manner (e.g. the changing nature of human rights), or that we can never know with certainty whether something exists. In educational settings, a realist educator would be more likely to assume a universal curriculum, as one underlying reality that is transmitted to students via a knowledgeable teacher regardless of students’ individual circumstances and context. An idealist educator would be more likely to assume that different people have different realities. From this perspective, while each student constructs knowledge, a teacher can play a role of collaborator, co-participant, and facilitator to meet the individual needs of students (Schraw & Olafson, 2002). Considering the natural problem solving culture of engineering, pragmatism can also be discussed as a method that welcomes multiple approaches in designing and testing solutions rather than requiring rigid adherence to a single ontological paradigm. In a sense then, we have added a radical position, as an ontologically neutral position assigned between realism and relativism as polar opposites on the continuum with respect to the role of reality (Ernest,
1993). It asserts that reality exists but cannot be known directly or unmediated and so knowledge can only be obtained through empirical or rational processes. In engineering settings, this neutral position based on pragmatism has been defined as successful basis for engineering development by expanding the perspectives in all disciplines of engineering (Richardson, 2003). On the basis of indicators commonly found in the literature, we developed a 12-item scale, as shown Table 3.

Table 3: Items of Beliefs about the Nature of Engineering Reality

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Realism</td>
<td>Engineering is a study of objectively existing physical entities and the relationships among them.</td>
</tr>
<tr>
<td></td>
<td>The statements made in engineering are true or false specifically dependent on the properties of those entities, independent of our ability, or lack of our ability to determine which is true.</td>
</tr>
<tr>
<td></td>
<td>Engineering has discovered a world, as a real structure, independent of our experiences and knowledge.</td>
</tr>
<tr>
<td>Pragmatism</td>
<td>Engineering is not about an observer-independent world; engineering knowledge is created by individuals in a historical and cultural context.</td>
</tr>
<tr>
<td></td>
<td>The value of constructed thought in engineering is assessed by the degree of its utility or effectiveness.</td>
</tr>
<tr>
<td></td>
<td>Engineering knowledge originates in the learner’s activity performed on objects.</td>
</tr>
<tr>
<td></td>
<td>There should be a universal curriculum based on core knowledge and skills in engineering.</td>
</tr>
<tr>
<td>Idealism</td>
<td>Individuals, in their role as co-participants in socially shared activities, develop certain common perspectives with regard to objects and event in engineering.</td>
</tr>
<tr>
<td></td>
<td>Groups of individuals carve the world up through a process of social interaction and social negotiation.</td>
</tr>
<tr>
<td></td>
<td>There is no world outside of human experience; the world is constructed or constituted by our discourse and theorizing.</td>
</tr>
<tr>
<td></td>
<td>It is meaningless to speak about the absolute reality of engineering objects.</td>
</tr>
</tbody>
</table>

Figure 3: A conceptual framework for Engineering-specific Epistemological Beliefs
Discussion

As shown in Figure 3, all the 44 items were developed for each of the three domains of engineering-specific beliefs. We were ensured that all relevant domains of engineering-specific beliefs described in the literature have been included without redundancy.

Because those 44 items were based on indicators commonly found in the literature, there was support for the face validity of the instrument. However, for more reliable instrument development, further research is called for to explore. For example, a pilot test needs to be conducted with engineering experts to share feedback regarding the instrument’s readability and logic. Informative feedback about the wording of the statements can be also incorporated. Furthermore, the three domains of the instrument need to be tested whether the instrument addresses what both engineering faculty and engineering students’ thought of engineering as a discipline.

References


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Virtual Instruments in dimensional metrology

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Abstract: During the last five years, in order to improve understanding of content related to "Coordinate Metrology", the Laboratorio de Metrología y Metrotecnia (LMM) from the Polytechnic University of Madrid offers its PhD students, as a course work, the construction of a virtual instrument. This virtual instrument simulates the imaging of a part to be measured by optical dimensional metrology instruments (microscopes, profile projectors, vision machines). The LMM provides students with images similar to those they would obtain with real instrumentation for the instrument adjustment and calibration process. Working with these images, students should determine the adjustment parameters of the virtual instrument. Once these parameters are set, the student can perform the proper calibration of the virtual instrument. Beyond this process, the instrument is already able to perform traceable measurement. In order to do that, LMM offers students some images of parts. Students should perform some measurements using those images and estimate the corresponding uncertainties.

Introduction

Professors of the Laboratorio de Metrología y Metrotecnia (LMM) from the Polytechnic University of Madrid have been teaching more than 30 years the subject "Dimensional Metrology" in doctorate programs. Currently, this course belongs to the Interuniversity PhD Program "Metrology and Industrial Quality" of the National Distance Education University (UNED) and the Polytechnic University of Madrid (UPM). Also, the LMM is the oldest Spanish laboratory accredited by ENAC (Spanish National Accreditation Board) to perform dimensional calibrations.

During five years, the LMM has offered its students the construction and use of a virtual instrument as course work into the subject "Dimensional Metrology". This instrument is a virtual scanner. The student receive, from the LMM, images corresponding to a real o
simulated scanning of a real part in a real instrument. The student will receive from the LMM such images electronically.

The objective to be achieved is that the student will improve the understanding of whole process of measurement (JCGM, VIM 3rd, 2008):

1. **design** and **construction** of the instrument,
2. **adjustment** of the instrument (VIM 3rd, 2008, 3.11),
3. **instrument** **calibration** (VIM 3rd, 2008, 2.39),
4. estimation of the **calibration uncertainty** and

Both the chosen instrument (scanner or microscope) and the proposed work plan permit, if student have access to real instrumentation, the repetition of the whole process on a real instrument. In the opposite situation, students can work exclusively with LMM generated images.

**Instrument choice**

Authors have chosen a commercial scanner capable of obtaining a photographic image of a plane measurand. Figure 1 shows the image of a scale obtained using the commercial scanner shown at the left: a Canon CanoScan LIDE 200. This instrument has a working area of 210 x 297 mm and an optical resolution up to 4800 dpi (dots per inch). Using this device the LMM has generated all the images sent to students.

In fact, it can be used any other optical instrument capable of providing two-dimensional graphic image of a measurand, as it could be a microscope equipped with a digital camera. In practice, the adjustment and calibration techniques presented to students were developed by LMM to be used with microscopes.

The main restriction introduced by the commercial scanner over a microscope or profile projector is that the part to be measured must have all geometry to check on the plane that rests directly on the scanner glass.

![Figure 1: Image of scale obtained with the commercial scanner showed on the left](image_url)
Two main reasons were taken into account when choosing the commercial scanner:

1. Students with a special interest in this work can repeat the whole process a real instrument: a commercial scanner (this device is an affordable one and easy to use).
2. Also, a commercial scanner has a relatively large measurement range (in an A4 scanner work area is 210 x 297 mm) which allows measurement of macroscopic size pieces. At the same time, it can be calibrated with macroscopic patterns (typically calibrated scales). In both cases, manipulation is easier and in the case of patterns, they can be easily manufactured using an inkjet printer and high quality paper.

Construction of the Instrument

The construction of the measuring instrument consists in writing and implementing a series of computer routines that perform four distinct tasks:

1. **Automatic detection of measurand edges** of and estimation of cartesian coordinates of their points.
2. **Adjustment of geometric elements** (lines, circles, ellipses, arcs or ellipse, etc ...) to the measurand edge points.
3. Determination of **distances and angles** between geometric elements.
4. **Construction of new geometric elements** from the existing ones (eg, a straight line passing through the centers of two circles).

Depending on student's particular interests in the subject "Dimensional Metrology", this part of the work can be directly delivered to the student (as routines written by LMM) or a work in a particular area such as the following can be proposed:

1. Edge detection algorithms.
2. Detection and elimination of outliers.
3. Adjustment of geometric elements.
4. Storing the information in a structured and easily retrievable database.

As an example of LMM routines available to students, Figure 2 shows the result obtained by fitting an ellipse to edge points, automatically detected, corresponding to an elliptical hole. LMM routines include edge detection algorithms and least squares techniques. The red curve represents the fitted ellipse and the blue one represents the residual distances between the edge points and the ellipse (with a x100 amplification). In this example, orthogonal regression techniques were used to make the ellipse adjustment. LMM routines also provide additional information about the correlation between the orthogonal distances. This information can be very useful for those students who want to center their work around uncertainty estimation.

To validate the work done by the student, the LMM has a large number of images of real measurands obtained with optical instruments (scanners, microscopes, etc ...) that can be
sent to student electronically. However, unless the student requests it, images generated by the commercial scanner of figure 1 will be sent to him.

Figure 2: Ellipse adjustment by orthogonal regression (units in µm)

**Instrument adjustment**

Automatic edge detection routines work with black and white images of the measurand. The scanner can directly provide black and white images or, when necessary, generate grayscale or color images that will be manually adjusted (contrast, brightness, saturation, etc...) and converted to black and white using standard photo editing software (see figures 3a and 3b). Unless student shows a particular interest in working with color or grayscale images LMM will send him only black and white images.

In any case, edge detection routines work with an array of zeros (dark) and ones (light) in which pixel position is known through the indices i and j of the pixel in the array. The subscript i grows when moving down along the image and the subscript j grows when moving right.
In order to have the pixel position information in x,y Cartesian expressed in units of length (mm) is necessary, in principle, the following:

1. Have an estimation of the horizontal ($p_X$) and vertical ($p_Y$) pixel size.
2. Take into account that $ij$ axes orientation do not match $xy$ Cartesian axes orientation. Therefore, we have:

\[
x = p_X \cdot j ; \quad y = -p_Y \cdot i
\]

Nominal pixel sizes are known when using commercial scanners because before using the device it is necessary to choose its resolution $r$ which is expressed in dots per inch (dpi, dots per inch). Usually, the horizontal and vertical resolutions are equal:

\[
p_X \approx p_Y \approx \frac{25.4 \text{ mm}}{r}
\]

However, when using an optical microscope (with an attached digital camera) to have an estimation of the pixel size is not so simple. In this case, pixel size depends on camera sensor size, its resolution (megapixels), lenses used, etc...

Therefore, the best alternative is measuring an object with known sizes, and from the data obtained, determine the horizontal and vertical pixel sizes. This is the alternative that LMM proposes to students.

LMM provide students with images (figure 4) of a square gauge scanned with the commercial scanner of figure 1. The side of the square gauge has nominal lengths equal to 100 mm. Using one of this images, students can measure the horizontal side length $L_{PX}$ of the square and the vertical side length $L_{PY}$. From these results they can estimate the horizontal ($p_X$) and vertical ($p_Y$) pixel sizes:

\[
p_X = \frac{100 \text{ mm}}{L_{PX}} ; \quad p_Y = \frac{100 \text{ mm}}{L_{PY}}
\]

Figure 4: Pattern of adjustment measured at two positions of 90°

If students have a real commercial scanner and want to work directly with it, the LMM can send a PDF document containing the image of the square gauge shown in Figure 4 and they can print it using an inkjet printer on photo quality paper. Working in this way,
student can manufacture its own square gauge and the can perform the whole adjustment process with a real instrument.

If the square gauge is measured in two positions, 0 and 90 degrees (see Figure 4), it can be observed that measured angles corresponding to the vertices A, B, D and E slightly vary from 0º position to 90º position. This is due to the fact that i,j axes may not be exactly perpendicular (see Figure 5), showing a small squareness defect $\alpha$.

![Figure 5: Relation between the cartesian axes x, y and (i, j) axes of the pixels](image)

By measuring angles A, B, D and E in two positions to 90 degrees, it is possible to estimate the squareness defect $\alpha$ of the scanner. An estimation of $\alpha$ can be obtained in absence of a prior knowledge of angles A, B, D and E. It is only necessary that these angles have a real value close to 90. Once an estimation of $\alpha$ has been obtained, the new equations relating the x,y Cartesian coordinates x, y with i,j indices i, j of the pixels in the array are:

$$x = +j \cdot p_x - i \cdot p_y \sin \alpha; \quad y = -i \cdot p_y \cos \alpha$$

In this moment, the student has been able to make a complete instrument adjustment. If he uses a virtual scanner, the images he worked with has been provided electronically by the LMM. If he uses a real scanner, the LMM has provided only a PDF file with the square gauge design, he has printed this file on a high quality paper and using it, he has performed the scanner adjustment.

This adjustment process needs a measurement standard (JCGM, VIM 3rd, 2008, 5.1): the square gauge. Therefore, it is not necessary this standard to be calibrated (JCGM, VIM 3rd, 2008, 2.39), remember that the adjustment process has been done using a nominal value of the lengths of the square sides sides (100 mm).

As a result, the x,y cartesian coordinates are still not traceable (JCGM, VIM 3rd, 2008, 2.41), since the scanner indications (JCGM, VIM 3rd, 2008, 4.1) have not been compared against a calibrated length measurement traceable to the unit of length (the meter of the International System of Units, SI). This activity is described in the following section.
Instrument calibration

Once the instrument has been successfully adjusted according with the process described in previous paragraphs, the scanner can be calibrated using a calibration procedure very similar to that used to calibrate profile projectors (CEM, 1999).

To those students who choose to use real scanners, the LMM provides them with traceable measurement standards that have been calibrated with a profile projector. The scale shown in figure 1 was printed on a high quality photographic paper and then attached to a flat metal plate no more than 2 mm thick. This type of scale can be easily made and easily calibrated in a traceable profile projector and ensures good dimensional stability over time.

Students using a virtual instrument receive images from LMM corresponding to the calibration of scanner shown in Figure 1.

Calibration is performed by placing the scale to the scanner X axis first and then parallel to the Y axis. For each axis, eleven distances between scale marks are chosen in such a way that nominal values of these distances cover uniformly the axis range (210 mm for the X axis and 297 mm for the Y axis). The student receives, therefore, two images. An image with the scale parallel to the axis X and the other one with the scale parallel to the Y axis Y. Also, the student receives the calibration certificate of scale issued by LMM.

For each distance, the student must perform ten repetitions of the distance measurement. To perform these measurements the students use the routines listed previously: edge detection routines, adjustment of geometrical elements and estimations of distances between geometrical elements. In order to get different indications in each of 10 repetitions, the working area chosen for each mark of the scale should vary. For example, we start using as working area the tenth top of the mark and in the following repetitions the working area will go down until you will have ten regions of scale mark that cover this mark completely. Sometimes, the LMM has supplied ten scale images obtained moving slightly the scale between one image and the following. In this case, the student should use the full mark to find the distances.

Using the certified values of the scale distances (written in the calibration certificate) and every one of the ten values corresponding to each one of the ten repetitions, the student must determine the calibration correction of the scanner axis for each nominal distance and estimate the corresponding uncertainty according to ISO-GUM guide (JCGM, GUM, 2008) and supplement 1 (JCGM, GUM-S1, 2008), using a procedure analogous to that used in the calibration of profile projectors (CEM, 1999). From these results, it is relatively straightforward to estimate an overall null calibration correction for each axis looking for the point where the sum of the absolute value of the calibration correction and its uncertainty reaches a maximum value.

But for those students with specific interest in the "Coordinate Metrology" and estimation of uncertainties in accordance with new techniques described in ISO-GUM Supplements 1 (JCGM, GUM-S1, 2008) and 2 (JCGM, GUM-S2, 2008), LMM propose them to determine
calibration corrections \( c_{PX} \) and \( c_{PY} \) for parameters \( p_X \) and \( p_Y \) described in the previous section, along with their uncertainties accompanied by the correlation coefficient between \( c_{PX} \) and \( c_{PY} \). Once this task is done, the new \( x, y \) Cartesian coordinates of a pixel can be estimating using the following expressions:

\[
\begin{align*}
    x &= +j \cdot (p_X + c_{PX}) - i \cdot (p_Y + c_{PY}) \sin \alpha \\
    y &= -i \cdot (p_Y + c_{PY}) \cos \alpha
\end{align*}
\]

Students who choose this way of working should also estimate the uncertainty associated with the evaluation of the squareness defect \( \alpha \).

**Measurement**

Once the instrument (real or virtual) has been calibrated, it and can be used to do dimensional measurements. In order to minimize the problems related with edge detection in images of workpieces (which are closely related to the reflectivity of the workpiece, the presence of scratches on its surface and contrast, brightness and saturation settings of the scanner) LMM uses only black measurands. The figure below shows some of them:

![Some measurands provide by LMM to students](image1)

Figure 6: Some measurands provide by LMM to students

On these measurands, students must measure some dimensions. Figure 7 shows the proposed dimensions to be measured in a particular workpiece sent to a student.

![Example of some dimensions proposed to be measured](image2)

Figure 7: Example of some dimensions proposed to be measured
If the student works with a virtual instrument, the LMM sends him some workpiece images similar to those of figure 6 obtained with the scanner of figure 1. If the student can work with a real scanner, then the LMM will sent a real measurand that has previously been measured in a LMM profile projector (although this measurement data won’t be sent to the student). This real measurand must be scanned by students in their scanners and, using the images provided by their instruments, they must perform the measurement asked by LMM. To carry out these measurements the student has access to routines listed in “Construction of the Instrument”.

**Uncertainty Propagation**

In metrology, each measurement result should be accompanied by its corresponding measurement uncertainty (JCGM, VIM 3rd, 2008), and should be estimated according with ISO-GUM guide (JCGM, GUM, 2008) and/or its supplements 1 (JCGM, GUM-S1, 2009) and 2 (JCGM, GUM-S2, 2008). Depending on student interest on the area of uncertainty estimation, different techniques can be proposed to the student in order to get a better uncertainty estimation.

In case of simple measurements, it is possible to apply directly the Law of Propagation of Uncertainty described in the ISO-GUM using a model function where the overall null calibration correction of the scanner is introduced (see section “Instrument Calibration”).

In case of complex measurement, it is necessary to use simulation (Monte-Carlo) techniques (JCGM, GUM-S1, 2008) and/or propagation of uncertainty matrices (JCGM, GUM-S2, 2008), see too (Cox y Harris, 2006) and (JCGM, 2009). In these cases, the overall null calibration correction is substituted by calibration corrections $c_{PX}$ and $c_{PY}$ and the squarness defect $\alpha$ which are used in conjunction with a model for coordinate measuring machines developed by LMM (de Vicente y Raya, 1999; de Vicente et al., 2005). Thinking on making the work easier, students are provided by LMM with the necessary routines to propagate uncertainties during the adjustment of simple geometrical elements (circumferences, lines, ellipses, arcs) using Monte-Carlo techniques.
Figure 8 shows the results obtained during the estimation of the measurement uncertainty corresponding to measurement of the diameter (15.6 mm) of a circular hole performed with the scanner of figure 1. The measurement results are the Cartesian coordinates $x_C$, $y_C$ of the center hole and the diameter $D$. Please note that the uncertainties of the center coordinates are close to 10 $\mu$m while the diameter uncertainty is only 5 $\mu$m. In figure 8, it can be observed the presence of positive correlation (the correlation coefficient was 0.44) between $x_C$ and $y_C$. Finally, the histogram of the diameter $D$ simulation shows that the probability density function of the diameter is very close to a normal distribution. On the contrary, $x_C$ and $y_C$ seem to follow distribution functions closer to triangular distributions.

**Result Analysis**

All measurements proposed to student were previously performed by the LMM with a traditional instrument like a profile projector. Because of that, the LMM have references values $z_0$ and their corresponding uncertainties $U(z_0)$ for each measurement proposed to students. When a student finished his work, he should send to LMM a measurement result $z$ accompanied by its corresponding uncertainty $U(z)$. From these values, a compatibility index $E$ can be evaluated. This index measure the compatibility between the result provided by the student and that provided by the LMM (the reference value). When the compatibility is high, this index is close o zero. When results are not compatible the index is higher than one:

$$E = \frac{|z - z_0|}{\sqrt{U^2(z) + U^2(z_0)}}$$
This compatibility index is widely used in metrology to analyze the compatibility between measurement results, corresponding to the same measurand, provided by different laboratories. If this index is lower than one, the measurement result is considered compatible and it is accepted that the result $z$ and its uncertainty $U(z)$ have been correctly estimated. If you exceed the value of unity, this indicates that problems have arisen either in the estimation of its uncertainty $U(z)$, which will subsequently be investigated and resolved.

Conclusions

The proposed working method to students, by default, consists in using images generated by the LMM in the scanner of Figure 1 from real measurands. This allows the student to work at home without any completary presential sessions at LMM laboratory, even if he does not have any real instrument. The work under these conditions is performed on a virtual instrument. The proposed work covers the entire metrological process, from instrument construction to final validation of measurement results.

Depending on the particular interest of every student, LMM can offer slightly different works to each student, with some work parts larger or shorter as a function of student interests. Thus, a student interested in the development of edge detection routines in specific applications (e.g., verification of sieves) will work harder in this area (edge detection) but will use a simplified method of estimation uncertainty. Instead, a student particularly interested in estimation of uncertainties in "Coordinate Metrology" will increase his workload corresponding to the section on "Measurement" but he will decrease the workload corresponding to the section "Construction of the instrument" using the standard routines supplied the LMM.

If the student has a scanner to work with and he wants to measure real measurement standards and workpieces, the LMM can provide him with calibrated measurement standards to be used during the calibration of his real scanner. Finally, he will be able to use his scanner to perform traceable measurements on real workpieces.

Results obtained during last years show that forcing students to confront real and complete problems (even using a virtual instrument) that involves the construction, adjustment, calibration and use of a measuring instrument permits the detection of gaps in student knowledge that otherwise will not be detected. In some cases, these gaps correspond to fundamental concepts such as adjustment and calibration that seemed to be well established but, actually, they were misunderstood by students. As a result, this way of working force the student to rethink and to reflect on these fundamental concepts and, finally, he end up dominating the field.

Also, this work of reflection of the student is very useful when he is preparing his doctoral thesis topic (remember that the subject "Dimensional Metrology" is a doctoral course). This reflection helps to detect weaknesses in his project and to clarify points that initially seemed to be clear but, after a period of deep reflection forced by a work like that described in this paper, some dark areas appear.
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An expert study of transfer in an Authentic Project

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Abstract: As engineering educators, we seek to equip students with the ability to apply their knowledge and understanding to solve novel problems. But how is this ability best developed? This study investigates such transfer by examining two different expert solutions to a complex process development project. The experts have different domain knowledge - one in chemical engineering processes, the other in mechanical engineering design. Solutions are examined using an emerging methodology termed “Model Maps”.

Context and Research Questions

Process development is a common and critical task for chemical engineers in industry; however, it is difficult to create activities at the university to give students practice where they are directly engaged in this task. Using a computer-based simulation, we have created a process development project for students, the Virtual CVD Project. The project has been specifically designed to provide the students an authentic, industrially-situated task which they can solve using the fundamental knowledge and skills that they have learned as undergraduates. This ability to transfer core understanding to solve novel problems is central to the practice of engineering, but challenging to develop and assess.

This Virtual CVD Project tasks students with designing and performing experiments to develop a 'recipe' of input parameter values for a chemical vapor deposition (CVD) reactor. The reactor deposits thin films of silicon nitride on polished silicon wafers, an initial step in the manufacture of transistors. The process development project is completed using a virtual laboratory. Based on the input parameters that are chosen, the computer simulation generates data for film thicknesses at locations that the students chose to measure. The output values incorporate random and systematic process and measurement error and are representative of an industrial reactor. The students use results from successive runs to iteratively guide their solution and are encouraged to apply sound engineering methods since they are charged virtual money for each reactor run and each measurement. They continue until they have found a 'recipe' of input parameter values that they believe yields acceptable reactor performance. There are four metrics that define favorable reactor performance: the students should perform as few of experiments as possible to develop a recipe that deposit films as uniform as possible, with the highest reactant utilization, and lowest reaction time. This project is complex and participants typically spend between 15 and 25 hours to complete the project. More information may be found in Koretsky et al. (2008).

In this project, there is no one 'correct' solution path. Through examination of over sixty student solution paths, we see that although no two solutions are the same, they can be
classified by three fundamental approaches. These approaches are labeled by the vertices of the triangle in Figure 1. In a sense, the triangle can be considered analogous to a ternary phase diagram and solution paths may be anywhere in the triangle, representing either a single method approach (at the vertices) or a mixed methods approach (inside the triangle). First, students may attempt to model the relevant physical and chemical phenomena affecting the process using first principles modeling (FPM). We define a model as the representation of a phenomenon that facilitates understanding and promotes further inquiry. These analytical models can be used to predict input parameter values that will result in desirable reactor performance - what we call a model directed run. Second, students may adopt a statistical experimental design (SED) approach. This method relies on empirical data to develop statistical models which relate input parameters to process performance metrics. The statistical model may then be used to predict how the input parameters impact process performance. SED includes such methods as Design of Experiments (DOE) and Robust Design using Taguchi Methods (Phadke, 1989). Finally, students may proceed in the solution path by 'intuitively' guessing and checking or, later in the project, tuning. This strategy relies, at best, on a qualitative understanding of the mechanisms driving the reactor. In this study, we focus on solution paths guided by FPM and SED.

![Figure 1: A triangle representing the three possible methods for solving experimental design problems](image)

Although both FPM and SED solution approaches are used in practice, they are seldom directly compared. The curriculum in chemical engineering is foundationally constructed to develop skills in FPM. Certainly understanding the fundamental phenomena governing processes is valuable; however, many practicing engineers resort to SED. Such input has led to recent integration of these methods into the curriculum (Koretsky, 2010), albeit often in a standalone manner. To confound matters, text books in DOE and Robust Design (Phadke, 1989) typically lack any discussion of FPM. To our knowledge, the literature lacks a description of the tradeoff between these two approaches and a discussion of what role each might provide in the solution to a process development project such as that presented in this study. It is unclear when, where and why each approach should be used on a given project. A balanced analysis that simultaneously considers both these approaches is needed to enable systematic curriculum design and to inform instructor feedback of development projects.
To address this issue, we observe and analyze the solutions of two experts, each with expertise in a different domain, as they complete the project. Neither expert has direct experience with the type of process upon which the Virtual CVD Project is based. One's expertise aligns with an FPM approach and the other's with an SED approach. In this way, our study is reductionist; we have selected individuals to intentionally investigate these two possible solution approaches and compare the similarities and differences.

This work is part of a larger investigation which seeks to answer the following research questions:

1. What characterizes the two different approaches (SED and FPM) these experts take as they complete the Virtual CVD process development project? Which components of their solutions are similar and which are different?
2. What approach leads to a higher quality solution? Are both methods suited for this project, or is either method preferred? Why?
3. Based on these observations, what conjectures can we make about engineering curriculum design, instruction, and feedback?

**Expertise and Transfer**

A clear goal of education is to help students move towards expertise. Following this goal, many studies across a wide range of domains have sought to characterize expertise (Chi, 1989; Cross, 2004). It has been found that experts possess well connected and rich knowledge structures regarding topics within their field of expertise. These knowledge structures, often referred to as schemata, facilitate a rich understanding of the problem and rapid recall of relevant “chunks” of information during the solution process (Bransford, 2000). When studying solutions to engineering design projects, it has also been found that experts tend to spend more time problem scoping than novices do (Atman et al., 2007). However, once experts choose a solution concept, they often stick with the concept throughout the solution process, whether it is good or bad (Ullman et al., 1988).

In the field of engineering where new technologies emerge daily, graduates need the ability to apply familiar domain content in new situations. This application of core knowledge to solve novel real world problems requires transfer. In order to understand transfer in this context, a new branch of expert studies has emerged, and has been classified by Hatano and Iganaki (1986) as ‘adaptive expertise.’ Adaptive expertise contrasts with ‘routine expertise’ in that it is flexible and may be applied to increase learning and performance in a wide range of new situations. Recently, efforts have been reported in the engineering education literature discussing how to increase adaptive expertise in students (McKenna et al., 2006) using pedagogies such as “challenge-based instruction, brainstorming in groups to generate ideas, receiving input from multiple experts in the field, and formative assessment integrated into powerful computer simulations” (Pandy, 2004, p. 9).

Our expert study is informed by this literature. We hypothesize that the experts will both: (i) execute their solution path in a sophisticated and effective manner, and (ii) rigidly adhere to a path that aligns with their foundational domain knowledge. By contrasting the
solution paths of experts with different domain knowledge, we seek to identify and compare a FPM approach and a SED approach. This knowledge can be used to develop strategies for increasing adaptive expertise in students.

**Methods**

We selected two experts based on the characteristics of their expertise and observed them as they completed the Virtual CVD Project as described above. The first expert has a doctorate in chemical engineering (ChE) and eighteen years industrial experience. He has been promoted regularly, culminating in a management position and a designation of “master engineer” in a global high-tech company. This expert has a robust understanding of the fundamental phenomena that govern the CVD reactor (e.g. diffusion, reaction kinetics) and has self-reported being “known in industry for his ability to apply fundamental engineering first principles to solve problems.” The second expert has a doctorate in mechanical engineering (ME) and over twenty years experience in design research and teaching at the university. In addition, he served as lead engineer and president of an outdoor recreation company whose primary product line was developed utilizing his design skills. This expert is a certified ‘Taguchi Master’ and has developed and taught courses on Taguchi’s methods of Robust Design.

While these experts had general disciplinary foundational knowledge, they lacked specific experience with CVD or related processes upon which the Virtual CVD Project is based. This lack of process specific experience allows for the study of adaptive expertise where the experts need to activate foundational domain knowledge to complete the project and cannot rely on specific experience from similar tasks. This research design provides an opportunity to study a project where the resources the experts need to solve the problem approximate the resources that can be developed in students.

Our research group has developed a methodology termed *Model Maps* intended to summarize the complete solution paths into a diagram showing critical solution components. Model Maps are created by researchers who transform the data contained in participants’ notebooks and other work products and the virtual laboratory database into information-rich, chronological visual representations which illustrate the development and use of models as the participants complete the project (see Seniow et al., 2010). Model Maps display the types of model components employed (quantitative or qualitative), their degree of utilization (operationalized, abandoned, or not engaged), and their correctness along a central problem line that also contains numbered experimental runs. A key for the different model map components is shown in Table 1 (page 4). The Model Maps analysis method was initially developed to analyse student solutions; 29 such solutions have been examined using the method. These solutions are not presented in this paper but we will allude to them in discussion of the experts’ solutions.

**Findings**

Truncated Model Maps of the two expert solutions are shown in Figure 1 and each of the expert’s solutions is summarized briefly below. Both solutions are detailed and with the...
limited space available, we focus this discussion on aspects of the solution that (i) address the research questions and (ii) will stimulate fruitful discussion and feedback at REES.

I. The Expert FPM Solution

The expert ChE approached the Virtual CVD Project by first performing a literature review to identify which fundamental principles could be applied to the process and to find typical input parameter values. This activity is shown in the box labeled “information gathering” in Figure 1a. He also used information from the literature to bound the design space, identifying potential combinations of input parameters that would result in unfavorable results. Based on this information, the ChE developed several first principles qualitative and quantitative models to help him understand the process. These models can be seen along the upper solution path line in figure 1a and they culminated in a single analytical model constructed of several FPMs shown in the dotted oval in Figure 1a. He then used this analytical model to predict the input parameter values for his first run, denoted by the square in Figure 1a, which signifies a model directed run. The expert performed seven more experimental runs during his solution. He used runs 2-4 to qualitatively verify his model and to further develop it (as illustrated by 5 new models). He fine tuned his input parameter values in runs 5-8 and then submitted the final recipe.

II. The Expert SED Solution

The expert ME immediately framed the Virtual CVD Project as an SED problem, and searched 8 sources from the literature for suitable ranges of input parameter values (see the ‘Information Gathering’ box). This information led to the development of a Taguchi L18 experimental design model and complimentary signal to noise ratio model. The oval shown in Figure 1b shows these as the first models operationalized by the ME and one of the team’s only primary models. The Taguchi method was used to set parameter values for 18 experimental runs in order to test the effects of six input parameters at three levels (a full factorial design would require 729 runs). The Model Map shows 13 additional ‘secondary models,’ not on the primary solution path line. These models were used by the ME to attempt to understand interactions between and relative effects of the input parameters. They were based on first principles but were developed in a qualitative and fragmented fashion which revealed a lack of fundamental domain expertise. For example, he had difficulty determining which of the many equations identified in the literature review were applicable and how they might be applied. Once the ME had designed his experiment using Taguchi methods and defined the ranges of input parameters, he conducted all 18 experiments in the design without developing further models (shown by the triangle and “1-18” in figure 1b). He then took the best performing run and used the model generated by Taguchi methods to improve the reactors performance in two subsequent ‘fine tuning’ runs. The expert ME voiced his desire to run another designed experiment but was constrained by time and submitted his ‘final recipe’.

Discussion

As predicted, each expert utilized the approach that corresponded to his expertise. As compared to student teams who pursue FPM or SED approaches, the experts enacted their
solution approaches earlier, more fluently, and in a more sophisticated manner. For example, no student teams have used a model to predict the parameters for their very first run or have used Taguchi methods to design and analyse experiments. The solution approaches employed by each expert had distinct advantages and disadvantages. The FPM approach allowed the ChE to converge on a solution quickly (i.e. in a low number of runs). The FPM approach also allowed the ChE to focus on the performance metric that he thought was most important (film uniformity) and achieve high performance regarding that metric.

Figure 1: Model Maps showing the solution paths followed by the two experts

Both overall solution paths pursued by experts in this study relied heavily on surveying the literature and developing models early in the solution process to facilitate an
understanding of the project. Both ended with 'fine tuning' runs. We argue that these are universal solution strategies that may be transferred to many process development problems. Accordingly, such front end ‘problem scoping’ skills and back end ‘tuning’ should be explicitly taught and modeled in engineering classrooms. Additionally, students should understand the relative merits and drawbacks for the FPM and a SED approaches. The appropriate method to choose depends on both the expected behavior of the process and the knowledge that the designer possesses. Although the experts in this study rigidly chose one method, from experience observing student teams, we feel that a hybrid FPM/SED approach is also a viable option for solving the problem. More investigation is needed to examine the potentially fruitful integration of these two approaches into one solution path.

Table 2: Comparison of the FPM and SED solution approaches and reactor performance

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
<th>CVD Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPM</td>
<td>SED</td>
<td></td>
</tr>
<tr>
<td>• Requires robust understanding of first principles</td>
<td>• Requires minimal understanding of underlying phenomena</td>
<td>• Higher uniformity / lower experimental cost</td>
</tr>
<tr>
<td>• Relevant first principles must be identifiable</td>
<td>• Can map a large area of the solution space</td>
<td>• Lower reactor time / higher reactant utilization</td>
</tr>
</tbody>
</table>

References


Design Engineering Technical Conferences and Computers and Information in Engineering Conference (pp. 1–6).


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**Abstract:** To improve the quality of people life and to reduce the risk of vulnerability of these, the engineering has some challenges. The engineering learning and engineering teaching should to create and to recreate them, that which is possible with the understanding and the approach to the reality or situation that the engineering students want to transform with students of other disciplines.

An example of these initiatives is the The Center of Education for the Development (CED). In this center professors and students of all the academic programs converge which I lower the pedagogic focus of education for the development. They have to design and implement practical in social responsibility as Engineer's project to the Neighborhood with Ingenieros sin Fronteras. These projects are learning spaces where the students have the possibility in classroom and marginal communities to apply knowledge among other disciplines and to acquire new knowledge, abilities and vital social and talkative competitions for their professional exercise and interaction with the other ones.

**Keywords:** Development education; interdisciplinary learning; developing communities

**Introduction**

The Corporation University Minuto de Dios leader in processes of applied investigation, social projection and teaching, from the Faculty of Engineering and the Center of Education for the Development (CED), which is the unit of Formation and Social Projection of Uniminuto, has proposed a strategic alliance to promote the human and social development in communities in high vulnerability situation, starting from the implementation of projects of social practice in engineering that you/they look for to strengthen and to articulate the professional knowledge with the popular knowledge and the social abilities of professors, students and marginal communities.
Context

For this it has been necessary to dialogue with disciplines of the social field as the anthropology, sociology and the social work, likewise to go to tools and technical of investigation and intervention characteristic of this areas with the purpose of that students and professors learn how to know and to carry out assertive readings of the different social realities, necessities and problems that requires the current society, so that this learning they are translated in successful projects that contribute to improve the quality of most vulnerable people's life.

It is not new to hear in the communities marginal bewilderment expressions to be had manipulated sense and little respected, with the academic government and/or practical implementation of projects that little to or anything came closer or they gave solution to the satisfaction of some of their basic necessities, due to the ignorance of the communities in their cultural, educational, environmental, economic and social part, likewise the lack and lack of assertive strategies of community intervention or superficial boarding, they allow them to be generated between the groups population perceptions and attitudes of rejection and indifference toward the professionals and students involved in some project type and of these toward the same community, situations that put in risk the good development and maintenance of a project with social character.

The above-mentioned is appreciations and conclusions that arise of the professors, students and gone away from engineering (agro ecologic, Industrial, Civil, and Systems among other) whose labor experience and participation in academic projects promoted by the Center of Education for the Development (CED-Uniminuto) they have given testimonies of its lived experiences, which have been key to identify the pedagogic, theoretical and practical difficulties in the formative processes of the education in engineering.

Example, student's of Civil Engineering Testimony.

Project, El Ingeniero al Barrio, City Bolívar, Bogotá - Colombia.

"People of the common one recognize us to the engineers for two aspects: the first one, as those people that take charge of to design and to build, housings, bridges, highways commercial centers, machinery, energy nets, of water and big technological works among other things, through the use and transformation of the natural resources for the "well-being" of the man, but they also perceive us as those characters distant, not very talkative, important and little experts of the next realities and of the felt necessities of people to which go directed many of our projects and big engineering works. It is not pleasing to perceive that our professional exercise finds it valuable for the material function and physics that we give to the things, but lacking of arguments, reflection capacity and critic, social sensibility and not because we want it but because we have not learned it. For that reason I consider that it is necessary that in our academic formation, be offered tools and strategies so much theoretical as practices that allow us to the future engineers to come closer assertively to the realities of our society, to unwrap us better as citizens and to create an imaginary one more positive of our work and professional image in the communities than we work..." R. Ciro.
Theoretical Framework and Methodology

This way, in the Center of Education for the Development of Uniminuto and is the engineering Faculty born the concern of ¿How to make of the engineering a practice more human?, that is to say how to make so that starting from the theoretical elements and technicians acquired by the students during its period of academic-professional formation, and that they are translated then in works, designs, models, and projects, first they respond to the true necessities of people and second they contribute to the construction in better communication ways where the engineering is hardly an excuse to generate better social nets and a better quality of life.

Consequently it is clear that the students should extend their knowledge beyond the physics, the chemistry, the mathematics, the drawing, and the systems, processes and models of quality, planning, administration, operation and production or knowledge strictly of the area of the engineering, and to acquire new instructions that allow them:

- Learn how to diagnose and to intervene a certain social context.
- Develop a bigger analysis capacity, reflection and critic in front of the social contexts that surround them and to the given situations.
- Make readings and assertive observations of the prevailing reality.
- To be civic and reflexive, critical and active professionals.
- To be professional assertive and socially responsible.
- To be able to Identify the premeditation of their to act.
- Understand others in their reality and the relativity of the same one.
- To be able to think interdisciplinary and to have the ability to communicate in multidisciplinary teams.

So much for the CED as the Engineering School are clear that the successful implementation and development of the mentioned aspects demand a concrete bet that also demands learning scenarios different to the traditional class classroom, analysis exercises and reflection around thematic concrete, of there the initiative of formulating a formation model that not responds alone to the new demands of the academic and social formation of the engineering students but rather also serves to the other academic programs of the academy.

In the "Model of Civic Formation" the students receive through a denominated course: develop Social Contemporary some first instructions that provide the students the necessary theoretical-practical elements, from the perspective of the Education for the Development, for the critical analysis of the social reality, developing discussions and reflections around thematic as: Models of Development; Poverty, inequality, injustice and social exclusion; Environment; generate; Intercultural ; I work Community; Peace and Non violent and Socially Responsible Actions. In second instance what intends is to work directly with the vulnerable population groups that learned, because they are the social organizations and the communities’ vulnerable outstanding scenarios of learning where the students know and they confront from face to the reality, of what way their academic formation, professional and personnel contribute assertively to social transformations.
These other classrooms (the communities, social organizations) of teaching they are materialized in the different practice projects in social responsibility, in those which diverse organizations and investigative and pedagogic initiatives, allow the students to maintain an I dialogue of knowledge with community leaders and families, so that when working jointly with the communities, abilities and learning are developed that contribute to improve quality of life for the less favored ones and educational quality for the professors and students.

This theoretical innovative initiative - practice is nurtured and he/she takes like with respect to the educator Brazilian and great exponent as regards humanity education Paulo Freire since of this, they can be recaptured several of the elements that proposes in its method dialogic and to apply them to the projects of he/she practices social, because this aspects they provide to the professor, student and community to conceive the theory and the practice as dynamic elements and humanity. Likewise one goes to the investigation, action, reflection, as dynamic methodology and to circulate.

The elements that take of Freire they are the following ones: The Dialogue, is the essential element of the dialogic method proposed by Freire, with activities promoted in the classroom around the dialogue so much students, as professors and communities go building, their perceptions, but also its to make, its way to live, of being unwrapped in a context and of being part of a historical moment. Likewise to understand even more east concept it is necessary that is carried out an approach to The Word, which is composed by two elements; the action and the reflection, which allow that it is materialized that I dialogue sustained in the class classroom and spend from the speech to actions, concrete projects but always contemplating the consequences of the same ones, in consequence has The Encounter that is a condition so that that I dialogue it is given, and this it should not only be seen as the physical space of meeting but as that space that gives the opportunity to know to the other one, it is the encounter the one that facilitates to students, professors and communities, to exchange knowledge, listens the histories, the experiences and the feelings of the other one, in the encounter feelings converge before certain situations that allow to identify and to know in a real way the situation of the other one, the students, they can express, to debate, to share their knowledge and to develop their creative capacity. Likewise in this encounter space A Reciprocity is generated, where for the community and the student implies more than the going and turn of the actions, more than the to give and receiving. The reciprocity is a road of acceptance of itself and of the diversities of the other ones and it is also a road in the taking of conscience that the confrontation with the diversity is fundamental for the interpersonal and professional relationships, it leaves fundamental of this encounter with the other one and its reality is that he/she doesn’t refuse the conflict and the difficulty, but rather keeping in mind these they should intend strategies of improvement. Once the student by means of her social practice has walked and lived the aspects in mention, you/he/she has arrived at a level of awareness of the reality that surrounds it and with her will be in the analytic capacity, that is to say of to make critical readings of the reality and to formulate actions assertively that they are translated in projects and innovative ideas that contribute to improve the quality of people’s life that you/they surround them without fear to confront the conflict and the despair.
The previous aspects when being worked articulately with the relating ones theoretical and practical implemented in field and classroom, they allow the students to find and to give a humanity character to the engineer’s professional exercise, it also facilitates him to understand to the student, professor and community that although at the moment one lives in difficult times in those that it seems that to cohabit with the difference is almost impossible and fear exists to come closer to the reality of the other ones, it is possible through strategies like the educational and social projects to understand and to experience that the diversity, the different thing, that opposed is it he/she makes people be better, because it imposes new challenges and new forms of acceptance and coexistence.

A prominent example of that innovative articulation between the theoretical thing and the practical thing in the mark of the Pattern of Civic Formation, it is the Project of Practice in denominated Social Responsibility:

"Family Environmental promoters" A Model of Training and Technician-social Work for the Human Development in Vulnerable Communities, I marry successful promoted by the program of Civil engineering and the project you practice in responsibility social Ingenieros sin Fronteras of the Center

of Education For the Development (CED) of UNIMINUTO, with the objective of to humanize and to bring near the engineering to the communities in high vulnerability situation. May of 2011

**Family Environmental Promoters, a successful experience of education from the engineering and the Pattern of Civic Formation.**

The course proposed by the alliance ISF and the CED of Uniminuto took place in the School Distrital José Celestino Mutis located in the sector of Mochuelo- Bajo, achieving the active participation of 20 families, of which 75% was women home heads, 15% men and other 15% young students of the grades tenth and eleven of the school; the assisting community to the course belongs to the stratum social 0 and 1 and they inhabit the neighborhoods Paticos, Lagunitas, Barranquitos and The Esmeralda of the sector of Mochuelo- Bajo located in City Bolívar, one of the poorest sectors in the District Capital, this participants was supported by 26 students of he/she practices social of Uniminuto belonging to different disciplines as civil engineering, engineering agroecológica, industrial engineering, marketing, logistics and social work, those which together with professors of the Faculty of engineering of Uniminuto and other academies like the University of the Andes - Colombia, and professionals of the social field of the CED, they promoted an education constructivist based on the socioeconomic and cultural reality of this community, improving this way its quality of life starting from the transmission of knowledge and the practice in field.

The course was divided in three fundamental axes: Social, Technician-environmental and Productive, for that which the thematic modules were divided in the following way:
### Chart 1. Thematic Modules study Family Environmental Promoters

<table>
<thead>
<tr>
<th>MODULE</th>
<th>ACTION AXIS</th>
</tr>
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<tbody>
<tr>
<td>The Paper of the Engineering in the Community</td>
<td></td>
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<tr>
<td>Assertive communication</td>
<td>Social</td>
</tr>
<tr>
<td>Social Responsibility and Citizenship</td>
<td></td>
</tr>
<tr>
<td>Successful experiences of Work in Community</td>
<td></td>
</tr>
<tr>
<td>Strategies and tools of Community Work</td>
<td></td>
</tr>
<tr>
<td>Healthy housing</td>
<td>Environmental Technician</td>
</tr>
<tr>
<td>Healthy environments</td>
<td></td>
</tr>
<tr>
<td>Legal and Sure housing</td>
<td></td>
</tr>
<tr>
<td>The water. Uses and Handling</td>
<td></td>
</tr>
<tr>
<td>Technical of Clarification and Disinfection of the Water</td>
<td></td>
</tr>
<tr>
<td>Manage and Use of Solid Residuals</td>
<td>Productive</td>
</tr>
<tr>
<td>Alimentary security and Urban Vegetable gardens</td>
<td></td>
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<tr>
<td>Ideas of Business</td>
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</tbody>
</table>

The innovative of this academic space of learning, is that it is based in an Social participative diagnosis carried out with the community and the leaning students of Engineering by Social Work, diagnosis that undergoes discussion and reflection and of which are possible to identify the population’s more felt necessities, of there that the initiative arises of implementing a course that he/she responded to the demands of the participant community.

**Finding and Conclusions**

The dynamics of the course resides in that as much the community as the student of Social Practice take the course in a simultaneous way in equality of conditions, since it is necessary that the students and the population beneficiary are qualified in the same topics so that in the practice days, the community begins its behavior change in front of the topics managed in the thematic modules, it is necessary to mention that this day of field work was organized so that to each participant family nucleus of the course he/she was assigned a couple of students which I lower the mark of the thematic ones you approach together with the family they; in the first place to observe a situation problem in the
housing, second, to intend jointly different solution alternatives and third to design and to materialize an action of improvement in front of that proposed by the World Organization of the Health in the concerning thing to Healthy Housing; work dynamics that facilitated a language and more human relationship among students, community and environment, that which allowed at the end of the course been as: improvement in susceptible residence spaces of generating illnesses taken place by the water, of origin, breathing or infectious, improving this way conditions of life in the families, improving their freedoms and achievements, increasing their sense of ownership and informing them of the responsibility that you/they have in front of the change of taking a healthy and sure life which begins with the leadership that has each one of them in their family and their community.

In a same way the course of Family Environmental Promoters became a space of dialogue of learning different to the traditional class classroom, allowing to the students besides applying knowledge characteristic of its professional formation in engineering, to carry out critical and reflexive readings of the reality, to acquire bigger social sensibility, to be civic and active professionals and also to develop social and talkative abilities, vital in the interaction with the other ones. Educational projects as the course in mention, are novel initiatives that articulate the interests and necessities of the vulnerable communities with investigation strategies, teaching-learning and social projection of the academy and the half education whose bets should be to generate and to address knowledge and actions toward principles of quality, and very common, it stops this way to achieve a positive impact and to impact significantly in the student's professional formation, in the critical and reflexive processes of people and in the improvement of quality of life of the less favored communities.

Finally it is important to continue involving other knowledge like the popular ones and those contributed by other professions among them the social work, the anthropology, because these they contribute methodologies and technical of investigation and intervention that contribute to improve the quality of formation technician - social and human of students and professors making them committed beings with their profession and socially responsible, it is also important to let that the engineering changes its formation scenarios, venture to formulate new learning classrooms and it is nurtured of other looks and knowledge because these they will allow him to respond indeed to the different challenges that it demands him the world.

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A model for evaluation of generic competences in engineering: Application to the problem-solving competence at UPM

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Abstract: The competence evaluation promoted by the European High Education Area entails a very important methodological change that requires guiding support to help teachers carry out this new and complex task. In this regard, the Technical University of Madrid (UPM, by its Spanish acronym) has financed a series of coordinated projects with a two-fold objective: a) To develop a model for teaching and evaluating core competences that is useful and easily applicable to its different degrees, and b) to provide support to teachers by creating an area within the Website for Educational Innovation where they can search for information on the model corresponding to each core competence approved by UPM. Information available on each competence includes its definition, the formulation of indicators providing evidence on the level of acquisition, the recommended teaching and evaluation methodology, examples of evaluation rules for the different levels of competence acquisition, and descriptions of best practices. These best practices correspond to pilot tests applied to several of the academic subjects conducted at UPM in order to validate the model. This work describes the general procedure that was used and presents the model developed specifically for the problem-solving competence. Some of the pilot experiences are also summarised and their results analysed.

Keywords: Competence assessment, problem solving, European Higher Education Area (EHEA).

Description of the project

The Technical University of Madrid has awarded a grant to the project “core competences in engineering. Proposal of a model for UPM” in the call for Educative innovation projects for the academic year 2010/11. This project is divided in four coordinated subprojects that pursue the following goals:

1. To analyze how core competences are treated and viewed by relevant national and international professional institutions and associations.
2. To analyze the industry’s view on the core competences of graduates from UPM.
3. To analyze how core competences are treated at UPM in relation with other institutions and associations.
4. To propose a generic model for the evaluation of core competences that may have application in the different fields of UPM.
5. To elaborate with the assistance of a specialized consultancy firm a tool for measuring the core competences of students.
6. To carry out pilot studies of the competence assessment model for each core competence in different university degrees and different educational levels.
7. To develop an Internet portal to help teachers in teaching and assessment of core competences.

The development of the Project is structured in five levels which objectives are related to the general goals of the Project (see Figure 1). Each one of these levels is divided into different tasks.

**Figure 1: Project structure**

**Level 1: Analysis of the treatment of core competences**

In this level the following tasks have been carried out:

- State of the art of the competence evaluation. Analysis of the methods applied by academic institutions and international professional associations.
- Analysis of the industry viewpoint on core competences of UPM graduates.
- Analysis of the management of competences in the different centres of UPM.
- Elaboration of a summary with information and recommendations about the teaching and assessment of core competences at the UPM.

As a result of these tasks a report has been written where the different competence evaluation strategies and the models developed by prestigious institutions are summarized. At the same time, this information has been compared to the results obtained from the analysis of the situation at UPM. This has allowed us to define the guidelines to follow in the next level of learning and evaluation of competences.
Level 2: Design of the core competences learning and evaluation model

The purpose of this level is to design a model for learning and evaluating core competences using the information obtained at the previous level. This model must be able to have an application on the different fields of UPM. The following tasks have been planned:

- To structure and prioritize the competence map for the graduate and postgraduate levels.
- To define the level of acquisition and control of competences.
- To define the learning and assessment methodology.
- To design a competence assessment system.

As a result of this work, the main characteristics of a test for the evaluation of core competences of students have been designed. Also the Internet portal of the UPM about core competences has been launched with relevant and useful information for teachers to help them to teach and evaluate core competences, that can be very useful to teachers that can apply the core competences assessment in their classes.

Level 3: Validation of the core competences learning and evaluation model

Various pilot studies have been launched in different colleges in order to validate the model for the following competences: oral and written communication, teamwork, leadership, problem-solving, creativity, analysis and synthesis, use of the Information and Communication Technologies (ICT) and organization and planning skills. Some of the programmed tasks are:

- To select subjects to apply the model. Taking into account that there are different levels based on the degree –for instance graduate and undergraduate levels.
- To define the levels of acquisition of the competence for three selected competences.

Level 4: Revision and feedback of the model depending on the results

The purpose of this level is to share the experiences carried out by the different working groups to enrich the model and improve its applicability in different contexts and fields of knowledge. The main tasks at this level are:

- Implementation of an interdisciplinary workshop to present the results of the pilot studies.
- Elaboration of a best-practice report.

The result of the work at this level will be the precise definition of the structure and contents that will be incorporated to the UPM Internet portal of core-competence assessment. This information will be the basis of all the UPM for teaching and assessment core competences.
Level 5: Development of contents and diffusion from Educational Innovation Portal

Once the model is improved by the previous experiences, the contents will be transferred to the Internet portal and a strategy to disseminate the contents of the portal and all the know-how acquired to the university community will be designed. A final report of the project will be prepared.

To organize the work developed by the different groups forming this Project, a group responsible of the coordination for the task is designated. Monthly reunions of the persons responsible for the different groups have taken place coordinated by the Vice Chancellor of Educatve Innovation.

Competence in problem-solving

Among the different tasks of the project, our group has been responsible for working out problem-solving competence. A problem is defined as a situation in which an individual wants to do something, but do not know how to achieve their goal [1], or a situation in which an individual acts with the purpose to achieve a goal using a particular strategy [2]. Also, a problem is a situation, quantitative or not, that requires a solution which the individuals involved do not know obvious ways to find [3].

Problems are situations that require individuals to respond with new behaviours. This activity is closely related to various skills such as analysis, synthesis, critical thinking, planning or creativity. Solving a problem involves tasks that require reasoning processes more or less complex and not simply a routine, associational task (as in exercise-solving).

The aim of our work is to promote among students the right mental attitude that stimulates their ability to learn, understand and apply knowledge in an autonomous way. The development of this competence requires an active approach by the students – "you learn to solve problems by solving problems". These problems must be appropriate to the level of the studies (but not mere exercises), the wording must motivate, not be direct and promote the development of concepts. In this regard, one must consider to select practical problems, meaningful and contextualized in the current reality of students and their future career. Learning should deal with the results and analysis but above all with resolution procedure. The process can be enriched by the diverse contributions involved by teamwork.

Among the various strategies for teaching problem-solving skills we have chosen the procedure originally proposed by Polya [4]. The reason is that it is a very general strategy that can be easily adapted to the usual problems of every field of knowledge. This strategy is structured in four steps:

1. Comprehension of the problem: Read carefully the problem and represent it in different ways. Detect both the significant data and the unknowns.
2. Planning the solving process: The most difficult phase. It is necessary to discover relationships between data and unknowns, and establish a plan for resolution. Practising, i.e., solving many problems, provides resources to tackle it successfully.
3. Implementation of the plan: If the problem-solving plan is well conceived, its implementation is usually relatively easy. However, it is common that changes have to be made during its implementation.

4. Assessment of both the solution and the procedure. This step is essential to improve learning in solving problems. You should critically examine and evaluate the results obtained as well as the procedure used. It is important that the details do not prevent short-term general ideas that have been consolidated.

The method must be first explained in class. The teacher has to provide the students a summary form including questions, suggestions and techniques that can help them in each of the four steps. Then, several problems are solved in class to exercise the procedure. At this point it is important to promote a participatory attitude among the students in order to facilitate their involvement in the problems, detect blockages and stimulate an appropriate attitude regarding problem-solving.

As part of the assessment procedures to measure the progress in problem-solving skills, students will be consulted on their perceptions of the usefulness of the method. The entries should evaluate the whole process, not just the result.

**Problem-solving procedure**

In accordance with the four rules procedure proposed by Polya we have developed a set of generic rules to guide the students on what aspects they should consider when solving a problem and in which order they must consider them. First of all we have elaborate a very generic procedure based on all the rules relevant to solve problems. This procedure should be able to be used with any problem, regardless of its approach or complexity. To be able to accomplish the problem completely the students must be able to take into account the following aspects:

- Recognize the problems within the whole situation and can express it in a clear and precise way.
- Decide to deal with the problem and are willing to try hard to solve it.
- Pick up, describe and organize all the information relevant for the problem.
- Figure out different ways to tackle the problem, study, in a preliminary way, the success probability of each one based on the principles and methods required by each alternative.
- Compare their information sources and can deal with data rigorously.
- Study several alternatives in a rigorous and justified way. Analyse the success probabilities and the advantages and disadvantages of each alternative.
- Choose the best alternative and apply it to solve the problem.
- Analyse the solution achieved, noticing if it is coherent with the conditions of the problem.
- Participate actively in the work group, particularly in the decision-making phase.
- Communicate the solution in a clear, practical and efficient way.
- Transfer what he has learned from the problem to real situations.
Each one of these aspects can be evaluated from 0 to 4 points (from E to A) applying the following criteria:

- 0 (E), unacceptable. The students has not taken into account the aspect considered.
- 1 (D), poor. The student has taken into account the aspect but in a erroneous way.
- 2 (C), fair. It is the minimum to be required from the student. He/She approaches the considered aspect correctly but does it in a disorganized way so much so that it may not be helpful to solve the problem.
- 3 (B), good. The student deals with the aspect in a correct and organized way, it clearly helps them to solve the problem.
- 4 (A), excellent. The student also justifies the work done and the alternatives they have chosen.

These rules are designed to be applied in problem solving but they are very generic. It is clear that there are hundreds of different kinds of problem, so applying the same rules to all of them it is not a good way to deal with the problem-solving competence. Sometimes this rules can be too vague, too wide, too difficult to evaluate with a 5-point scale, etc. To deal with this situation we have restricted ourselves to the sort of problem that usually appears in the engineering studies. This includes, however, a wide variety of problems depending on the subject and the year of the studies. While during the first year the problems usually are mere exercises where the students usually have to apply a quite direct method to solve them and often they only have one way to solve it, in the top courses of a university degree the problems are much more difficult, very near to life cases, where the statement of the problem is complex, and the solution can be approached in several ways, some of them much more efficient than the others. Thus, we have divided the problem-solving competence in four levels, each one with his proper procedure and with different rules –always based on the above described rules.

At this stage of the project we have limited to the level-1 rules. We have also designed a pilot study of the use of the students of this rules.

### 3.1 First level problem solving procedure.

The first-level problem-solving rules are designed to be applied mainly to the first and second semesters of engineering studies. It deals with problems, more complex than a mere exercise where the wording includes more information than the strictly needed, the development of the problem is long and the students have to choose between two or more ways to solve the problem (usually one correct and the other not).

In the following table you can find the rules used to the assessment of the problem solving competence. It is clearly shorter than the initial one and the evaluation steps have also been reduced.
Once we have designed what we think it is a good problem-solving procedure the next step is to make the students use it and evaluate the suitability of the method. To this aim we have prepared a group of pilot studies. In these studies the procedure will be explained in detail to the students and the teacher will solve some problems using the rules to show the students their advantages. Once the students have become familiar with the rules the teacher will propose a problem to be solved applying the problem solving rules. This

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Unsatisfactory (D)</th>
<th>Acceptable (C)</th>
<th>Advanced (B)</th>
<th>Excellent (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehension</td>
<td>The information obtained is clearly not enough and/or irrelevant.</td>
<td>The relevant information – data, variables, conditions needed... is identified but in a disorganized or unproper way.</td>
<td>The relevant information of the problem is identified properly.</td>
<td>The student also justifies the need for and utility of the information.</td>
</tr>
<tr>
<td>Application of the method</td>
<td>The method has not been applied or its application is not correct.</td>
<td>The method has been properly applied but in a disorganized way and without explanations.</td>
<td>The method has been applied systematically but it does not have explanations.</td>
<td>All the steps have been explained.</td>
</tr>
<tr>
<td>Justification and clarity</td>
<td>There are few – or even no- explanations that make the reading and understanding of the resolution of the problem easier.</td>
<td>There are some explanations but they are not well organized and have little mistakes.</td>
<td>All the explanations needed are included in an organized way.</td>
<td>The explanations are also expressed in a clear and rigorous way. The solution is highlighted.</td>
</tr>
<tr>
<td>Results</td>
<td>The results are not present, are not correct or are incomplete.</td>
<td>The results are correct and complete with unimportant mistakes (numerical or notation).</td>
<td>The results are correct and complete. They are properly expressed (adequate notation and unities).</td>
<td>The results are also expressed clearly and rigorously.</td>
</tr>
<tr>
<td>Efficiency</td>
<td>The possible alternatives are not present and the procedure chosen is a bad one.</td>
<td>There are more than one alternative but the chosen one is not the best.</td>
<td>The alternative chosen is the best one.</td>
<td>All the alternatives are presented and reasoned out. The choice is justified.</td>
</tr>
<tr>
<td>Critical Analysis</td>
<td>Neither the results nor the procedure are checked.</td>
<td>The results are checked and they are coherent with the conditions of the problem but the procedure is not analysed.</td>
<td>Either the results and the procedure are checked.</td>
<td>The solution is checked and verified. Its application is extended to other contexts and generalized. The procedure is analysed and some improvements are proposed.</td>
</tr>
</tbody>
</table>

**Pilot study**

Once we have designed what we think it is a good problem-solving procedure the next step is to make the students use it and evaluate the suitability of the method. To this aim we have prepared a group of pilot studies. In these studies the procedure will be explained in detail to the students and the teacher will solve some problems using the rules to show the students their advantages. Once the students have become familiar with the rules the teacher will propose a problem to be solved applying the problem solving rules. This
problem will be evaluated both, by the student and by the teacher in order to obtain the degree of comprehension of the rules. Finally the teacher will conduct a survey among the students to know how comfortable do they feel with the procedure and whether they think this way of solving a problem is better.

At this stage of the project we have designed the pilot studies but we have not applied it yet. We plan to conduct the pilot study in the following subjects:

- Physics, Mathematics, Statistics, second semester of the Degree in Environmental Engineering.
- Electronics, second semester of the Degree in Forestry Engineering.
- Chemistry, first semester of the Degree in Environmental Engineering.
- Mechanisms, fourth semester of the Degree in Aerospace Engineering.
- Mechanic, third semester of the Degree in Aerospace Engineering.

The study will be finished at the end of the next academic year. However, this summer we will have some preliminary results of the studies carried out in the subjects of Physics and Mechanism. These preliminary results will be explained in an oral communication at the "Edulearn" meeting.

**Conclusion**

The UPM is making a great effort to develop and evaluate the core competences of its students. In this paper we have shown the methodology that is being used to achieve this goal. We have focused in the problem-solving competence. We have shown the assessment rules we have developed and how we have adapted them to the first years of the engineering studies. Finally we have proposed some pilot studies that will be carried out within the next months.

**References**


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A freshman project based computing engineering course: team work and innovation as a focus

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Abstract: This article presents a set of oriented actions in a freshman course geared towards reinforcing teamwork, communication and innovation abilities in computing engineering students. This article presents the structure of a freshman computing engineering course, activities’ dynamics and assessment issues. In a “non-content” course, the students face three teamwork challenges: two 3-week mini-projects with a commonly proposed challenge and a 12-week project proposed by students in a general framework. The three project activities are driven by the OCDIO proposal (inspired in the CDIO approach with an initial Observation stage): engineers Observe to understand a problem scenario, Conceive a proposal in order to solve some issues of this scenario, Design the system proposed, Implement and Operate it. The observation of the Operation stage could start a new cycle OCDIO in a continuous improvement process.

The dynamics of the team’s composition, the different steps of the project’s development, the management of limited resources and the evaluation tools and scenarios, can contribute to reinforce the teamwork, design, communication, and innovations skills of computing engineering students. This article presents these activities and some examples of evaluation results.

Introduction

In recent years a great effort has been made to form and develop student’s abilities in engineering schools. Teamwork, project-based work and communication skills are underlying this effort [Sullivan 2001]. In different scenarios, an ever increasing amount of “active-learning” methods [Hundhausen 2008][Ramírez2010], with promising results, have been incorporated.

The aforementioned efforts are initiatives to align the educative objectives with the new characteristics of the students and the professional environments. The systems and computing engineering is specially affected by continues changes in technologic context [Trew2010]. Some of the most common challenges in education perspective are related to the type of jobs and the jobs instability evidenced in this context. Affirmations such as “We are currently preparing students for jobs that don’t yet exist, using technologies that haven’t been invented yet, in order to solve problems we don’t even know are problems
yet." [Ball2008] enhance the challenges in education perspective. Curriculum renovations are fundamentals to continue a high level formation to intensify the leadership skills [Baravalle2010].

This article describes a course for systems and computing engineering freshman students. It is part of the recent curriculum renovation of the engineering school. A “project line” was introduced in the 4-year engineering programs that, in three project-based courses (in first, fifth and last semesters), seeks to enhance student’s skills in teamwork, communication, design and innovation in a “project driven” context [Hernández2004].

This course is inspired in the CDIO approach (Conceive, Design, Implement and Operate) [Malmqvist2010], with an important Observation stage introduced explicitly. This course uses the OCDIO approach for project driven work. One of the main characteristics of our proposal is that students have two different work teams with two different projects simultaneously during the semester. The preliminary results after two years of working with this new format, are very interesting with respect to engagement in teamwork, time management and communication skills.

We present, in the next section, the course structure and activities along the different projects. After, the assessment issues are addressed and, at the end, some comments and conclusions are presented.

The course

The context of the course is important: The students (with exceptions) have not met their classmates previously, they are 11% women, in average 17 years old with excellent academic results in their high schools (the highest 4% of the country), and 20% come from outside town.

The course is intended to be an integration course to the university, to the program and to the systems and computing engineering style of thinking and working. The design of this “non-content” project based course uses learning by doing strategy.

The course is developed during a 15-week long semester in which the structure, illustrated in figure 1., is proposed, with three projects, a series of conferences by guest speakers and a series of business visits.
The course is organized around three projects. A Project is described in terms of its objectives, its assignment of limited resources (especially time and teamwork) and the deliverables that demonstrate the project realization. As we can see in Figure 1, we have three projects during the semester: two short “sprint” projects (Sprint-P, 3 weeks long) and a long “endurance” project (Endurance-P, 12 weeks long) in a 15 week semester. In the proposal of this course, a very important factor is the fact that students are required to manage two different projects with two different work teams simultaneously. We are looking to create conditions so that the students have a “real” experience of having to manage projects, work teams and communication of results to third parties. The goal is to make the student have a controlled experience of the professional exercise in a context related to technology issues.

The following sections present more relevant characteristics about the two types of projects: the “Sprint-P” and the “Endurance-P”.

The “sprint-projects” (“cycles”): A Sprint-P is a 3-week long project with special conditions for its accomplishment. The four team members are chosen by the teacher (looking to have a good mix in terms of provenance and gender) and the objectives and deliverables are clearly defined. The most important result evaluated is not the deliverable of the proposed challenge itself (which is certainly evaluated) but the team members organization to achieve the deliverables and the intra-group communication mechanisms used.

In order to minimize the risk of failure (and consequently the student’s motivation) a series of activities that guide the student in the project’s development have been designed. These activities, as can be seen in Figure 2 are: an opening session (Observe), an activity supporting the subject of the project’s objective (Conceive, Design), teamwork outside of...
class (Implement), a closing session with a presentation to third parties and a “post-mortem” session (Observing the project result).

The opening session includes the description of the project’s objectives, the context of the proposed challenge, the definition of the work groups and an initial phase of the plan for developing the Sprint-P. The support activity varies according to the subject to be developed. Its goal is to complement the information obtained both in the opening session and in documents, to support the design activity. Therefore expert guest speakers are invited, lab practices are performed, visits to businesses and demonstrations of partial or total solutions to the problem addressed by the Sprint-P are presented. The demonstrations should be student projects of advanced semesters analyzing a similar problem of the Sprint-P. This allows for an articulation of results from different courses and a deeper knowledge about the subjects and abilities that will be developed throughout the curriculum. The team work (outside of class) is shown through design reports and presentations of the proposals, their achievement and results. The closing session is an oral presentation of the written work that is handed. This presentation includes the process followed to develop the Sprint-P, the difficulties, the achievements, and it is supported by material such as videos, demos and wiki publications. During this closing session evaluation by the teacher, teaching assistants, the students and external persons (teachers and advanced students) is performed. The observation of the process, the impact of the organization of the group work and the results obtained are matter for reflection and for a closing report of the project.

There are not strong restrictions with the Sprint-P project’s topic. They are related to information technologies. There is no intention of being complete in the coverage of ICT areas or the problems in the systems and computing engineering profession. The purpose is rather, in the first project to come into contact with the process of addressing an
engineering problem with ICT, and in the second one, framed in an application area, to be more purposeful and to show the added value of the proposal. Sprint-P 1. A Process of ICT solution: A relatively simple context for the students is used (for example: computer games using a game motor easy to use). The idea is that, given an objective, a process that structures simpler activities with easily evidential resources and deliverables to construct an available solution for one or more users is guided. Regarding a given subject (energy consumption, for example) to propose, design and implement a solution (a computer game with a simple game motor). Rather than the actual software development, an analysis of the work, the conception of a solution, the design of the components and their coupling as well as an evaluation of its functioning is expected. Sprint-P 2. ICT application in an area: With the knowledge and basic programming abilities (second half of the first programming course [Villalobos 2008]), the work groups should, in a controlled technological context, address a subject and propose and prototype solutions that add value. Examples of these areas are: visual computation, distributed computation, mobile computation, databases, software engineering, human-machine interaction. An example of a controlled context: Processing (http://processing.org) as a quick prototyping development environment.

The “endurance project” (ExpoAndes): The Endurance-P is a 12-week long project intended to illustrate the complete cycle of a computing engineering project. It is a transversal project in the whole engineering school that is intended as a first immersion into engineering projects, team work skills, communication and innovation with engineering. Every semester 600 students participate in this project under a general coordination. In a general context, the students propose possible projects and, around these proposals, they form 4-member work groups that will cover the project stages (Observe-Conceive-Design-Implement-Operate) ending in a presentation of the project results in a fair (ExpoAndes) open to students, teachers, parents and external visitors [Hernández 2008]. All the freshman introductory courses (3-credit) in the Engineering School work on the “endurance project” (ExpoAndes) and each semester the teacher’s team chooses a general subject for the term (Example: Sustainable cities, Engineering&Health). The computing engineering students seek for proposals with ITC added value framed in the “semester’s general subject”

In this project, the process, the communication of partial results (oral and written), the team work, the final presentation in the fair and the general balance of the process are evaluated. There is a crossed evaluation of the students at different moments of the project and external feedback and evaluations of teachers and graduate students.
Below, we present the different activities oriented to support the OCDIO structure in the Endurance-P.

**Observe & Conceive:** The process of observation, and the conception of the idea, in the context of the proposed “general subject”, is made in two steps:

- **Individual exercise:** Based in expert conferences, bibliography and direct observation activities, each student must propose a problematic situation to address and the potential added value of ICTs.
- **Ideas Fair:** In a session with the individual proposal shown in a poster, the students express their favorability for the different ideas and at the end of the session the teams of four students are defined on the basis of the most accepted proposals.
- **Team observation work:** Student teams observe situations that allow them to conclude that they can give society an added value using what they learn in computing engineering. Based on this observation the team should formulate the team proposal draft in a formal document.

**Design & Implement**

With transversal activities of engineering, students design the computing prototype of their proposal. Even though design and implementation advances are shown in the engineering introduction courses, at the end of the semester, students present to the public the results of their design and conception during ExpoAndes. ExpoAndes is a fair of innovation, teamwork, and entrepreneurship, where the different groups of students show an innovative proposal that allows them to solve a problem derived from an identified necessity. Students that present their prototypes in ExpoAndes have to demonstrate that
they have acquired an initial approximation of their own engineering methods and tools: observation, measurement, conception, design, construction and validation.

One example of this "Endurance-P":

**AR-E: Augmented Reality Education; Systems and computing Engineering**

**The problem:** How to enhance the learning process based on 3D interaction. The challenge stated by the students was "how to enrich computer-based exhibitions with augmented reality"

**The proposal:** Based on web cam pattern recognition of printed 2D pieces, the system can display 3D objects whose projection follows the 3D position of the physical pattern. The demonstration application was a virtual museum. The system shown integrates a pattern recognition library and 3D models with an interaction proposal to illustrate the virtual museum’s idea.

In the fair (a whole day) students exhibit their projects in stands located in the engineering building. Around 3000 people come to the ExpoAndes fair (parents, high school students, students and professors), 150 stands show the prototypes of the 600 freshman students of the engineering school, and an evaluation of the presentation is made.

**The assessment of the course**

Throughout the different projects (the two Sprint-P’s and the Endurance-P) the OCDIO approach is present. The assessment tools try to follow these steps. We find two main assessment events:

- Oral communication (presentations, poster sessions, demonstration sessions, fair)
- Written communication (design documents, project final report).

We try to apply the same set of criteria for all of them, with different relative weights, depending on the step of the project. These criteria evaluate different aspects of the project:

- Creativity/Novelty of the proposal’s idea to solve the challenge
- Potential impact in society (more for the Endurance-P)
- Review of similar projects, potential market
- Project Goals
- Engineering Design
- Prototype demo
- Quality of presentation
- Communication abilities
- Team work

The teamwork aspect, which is very difficult to observe, is addressed with an intragroup self-assessment tool, ex-post the project. Each student should assess the participation of
each member of the team (including his/her participation), and identify the key aspects that should be modified next time. This individual feedback which has no effect in the grade is made as a part of the project post-mortem activity. Below we can see some examples of these messages.

“your participation in the project received the following perception of your team members”:

“He lacks communication with the team but he fulfilled his tasks” (2.5/5; 4/5; 3.5/5)

“He participates in the project, but without engagement and initiative” (5/5; 3.7/5; 3.5/5)

“He was as a team’s head; His participation was active, with ideas and responsibility” (4.5/5; 4.2/5)

For the oral communication, we have different sources of assessment:

- Students themselves (sometimes individually, sometimes in teams) do a cross evaluation
- External invited experts (graduate students, and professors)
- Teaching team

In the written communication, the assessment (and feedback) is made by the teaching team.

At the end of the course we ask the students directly about their perception of the contribution of each main activity to their team work and communication skills. They say that the contribution of the “Endurance project” is greater than the “sprint projects” for the team work. They ask for more support to enhance their communication skills and orientation in order to give continuity to the endurance project.

**Comments and conclusions**

We described in this paper a project based course for freshman computing engineering students. The aim of the course is to give an immersion environment to project driven engineering activity, and to enhance team work, innovation, and communication skills in the students.

The project activity in the course seeks to provide the student with a wide vision of the engineering job, based on their student participation in different kinds of projects with different teams, where practical and active learning occurs throughout the semester. Students are invited to learn how to plan their resources (mainly their time), also how to develop in an autonomous way (with the support of the teaching team as a guide) a set of activities (decide to deepen their knowledge in some specific topics, to consult experts), as a team, in order to achieve their project’s goals.
The parallel development of two projects with two different teams seems to have a deep impact in the student's experience acquisition. We have no complete evidence of the progress of team work behavior of the students, but the progress of the feedback comments through the semester is a good sign in this direction.

The innovation aspect is present in the three projects but, especially in the endurance project. The presentation of the project’s proposal in the context of other similar projects, and the exhibition of the “functional prototypes” to a wide public are challenging and motivating to make the proposals more ambitious in the innovation aspects.

We should do a more rigorous evaluation of teamwork and innovation in this freshman course, in order to have more evidences of the impact in the “behavior” of the same students as “advanced students and professionals”.

**Acknowledgements**

This course is developed in the context of the innovation initiative of the Engineering School. We appreciate the permanent contribution of Prof. Catalina Ramírez to the design of assessment tools of this course.

**References**


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Session 2 - Wednesday afternoon

Topic: EER – Chair: Llewellyn Mann

Strategic pathways to engineering education research: a top-down case study

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Abstract: In this paper we first present a line of research into potential pathways to facilitate broader participation of engineering educators in education research, one that we propose to develop in various international contexts. Then in the main part of the work we focus on an application of our approach in one specific national context, that of Malaysia. A top-down pathway is proposed to describe recent developments in engineering education research in Malaysia. Analysis of publications from 2000 to date has indicated an increase in engineering education research since the introduction of outcome based education in the country. A Community of Practice in engineering education is beginning to emerge and some research universities are establishing research groups and centres of excellence for research in the field.

Background

At both the 2008 REES in Davos and the following one in Cairns in 2009, concern was expressed about the need to find ways to encourage more engineering faculty to become involved in engineering education research. Subsequently a small international group of researchers began exchanging ideas online around the issue and these exchanges later came to assume the form of the seven Strategic Pathways to Engineering Education Research (EER) that are outlined in Table 1.
Table 1: Seven strategic pathways to engineering education research

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Designation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathway 1</td>
<td>Scaffolded Paths</td>
<td>Classroom-based research which may often lead to case-study or “show &amp; tell” papers at subject-specific engineering conferences.</td>
</tr>
<tr>
<td>Pathway 2</td>
<td>Linking with the world of enterprise</td>
<td>Work with engineering practitioners in companies.</td>
</tr>
<tr>
<td>Pathway 3</td>
<td>Outreach</td>
<td>Attracting a larger and more diverse intake to undergraduate engineering courses through linking with schools or direct outreach to young people</td>
</tr>
<tr>
<td>Pathway 4</td>
<td>Spontaneous Generation</td>
<td>Where a department or institution spontaneously develops EER</td>
</tr>
<tr>
<td>Pathway 5</td>
<td>Top-down initiatives</td>
<td>EER arising from structural changes in the educational system.</td>
</tr>
<tr>
<td>Pathway 6</td>
<td>PhD studies</td>
<td>Provision and structure of PhD programs for engineering or social science graduates provides a path to EER.</td>
</tr>
<tr>
<td>Pathway 7</td>
<td>Technology Stewardship</td>
<td>Selecting, designing or adapting tools to facilitate learning, evaluation and competence-building on engineering courses.</td>
</tr>
</tbody>
</table>

The overall aim of the Strategic Pathways approach is to produce data and conclusions which will be of use to those involved in engineering education at departmental, institutional or national policy level who are interested in developing strategies to encourage engineering educators to pursue the scholarship of teaching and learning in addition to their specialized engineering research.

Although our overall research questions would be general ones about the potential of this framework, in the present work we confine ourselves to considering just one of the proposed pathways and hence we formulate it as:

Can a study based on Pathway 5 of the Strategic Pathways to EER framework provide useful lessons for institutions wishing to encourage the practice of research in this area?

**Methodology**

As we believe this topic has not been explored systematically up to now we have opted for an exploratory qualitative methodology (Creswell 2002), which in this paper is in the form of a case study of the Malaysian EER context using bibliometric data.

**The Strategic Pathways Framework**

Before considering the framework itself, a word about the underlying theoretical concept: our potential members are typically engineering faculty members whose research activity has been in engineering and who identify with a community of researchers in their specialist area but often feel less comfortable about participating in educational research. Although various approaches to the social character of learning can be found in the literature (Bandura, 1977; Vygotsky, 1978), Lave and Wenger's characterization of legitimate peripheral participation in a community which may lead with time to core participation seems a useful way of viewing the entry path of these potential EER community members (Lave & Wenger, 1991). This framework this has been sucessfully...
used as a lens to study analogous processes in a number of relevant fields ranging from technology, where John Seely Brown uses it to describe learning process of new researchers the Palo Alto Research Center (Brown and Duguid, 2000; Schrage, 2002), to the preparation of engineering graduate students for faculty careers (Crede et al, 2010).

Given that our first objective was to suggest pathways that would help lead non EER practitioners into EER, we started to look at ways of defining a relatively small number of broad pathways – i.e. aiming to give priority to simplicity rather than exhaustive completeness in our framework. We initially looked at attempts to map recent or future research trends; for example, there have been a number of approaches to mapping EER themes in publications over the years (Wankat, 1999 and Wankat, 2004; Whitin and Sheppard, 2004; Osorio & Osorio, 2005; Osario & Osario 2002; Borrego, 2007 and Jesiek et al 2011). However, these approaches tended to give priority to analysis of journal articles i.e research by relatively experienced EER practitioners whereas we are more focussed on novice EER practitioners who might be expected to begin their involvement at the level of conference papers. Also they tend to present exhaustive lists of research categories (recent examples range from 20 to 38 separate categories). Similarly there have been attempts to propose EER research agendas (Demetry, 1980 and NEERC, 2006) but again the focus here has been on proposing research frameworks for practiced researchers rather than novices.

Consequently we have opted for subjectively defining 7 potential strategic pathways from our own experience of attending EER conferences over a number of years. This is one aspect on which we would welcome discussion during the REES session.

Pathway 5 case-study

In the present paper we exemplify one of the proposed Strategic Pathways, number 5, in the case of top-down support for EER in Malaysia as a result of the influence of the ABET Engineering Criteria 2000 and the Washington Accord.

**Historical context of engineering education in Malaysia**

Engineering education in Malaysia started as early as 1957 and today 25 public and private universities including four foreign branch campuses are providing engineering education in Malaysia (Mohd Yusof & Mohamad, 2010). To enhance the international mobility and global employability of Malaysian engineering graduates, efforts were made by the Malaysian Engineering Accreditation Council (EAC) to be accredited by international accrediting agencies and becoming a member of the Washington Accord was a means to achieve this objective. EAC was accepted as a provisional member of the Washington Accord in 2003 and the existing Engineering Accreditation Manual was revised to pave the way for Outcome-based Education (OBE) implementation as required. The implementation of OBE was seen as a remedy for some of the weaknesses attributed to the traditional engineering education programme and in 2009 EAC Malaysia was finally admitted as a full member of the Washington Accord (Mohd Yusof & Mohamad, 2010).
Top-down directives may provide opportunities that lead to research activity in areas that were previously untried. This was the case in Malaysia when the Malaysian Ministry of Higher Education together with the Engineering Accreditation Council made a decision to adopt outcome based education (OBE) as the guiding principle in the design of all new engineering programmes in tertiary education institutions beginning from 2004. To help characterize the development of EER in Malaysia we will consider the following aspects:

1. EER publication trends before and after OBE;
2. the focus of research interest after OBE;
3. researchers involved;
4. research designs used;
5. available support.

For this particular case study, the information on how EER came into being through Strategic Pathway 5 was gathered from 33 papers on engineering education in Malaysia (Appendix 1) that were published in the various conference proceedings and journals. Although, some of the papers from post OBE implementations may not be related to OBE directly, we believe they do reflect the research culture on EE at this time.

**Findings**

The distributions of papers (and percentage in brackets) reviewed are shown in Table 2 and corresponding chart. As expected, publications intensified after the complete cycle of the OBE implementation.

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011(April)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-OBE implementation</td>
<td>-</td>
<td>-</td>
<td>2(6.3)</td>
<td>1(3.1)</td>
<td>0(0)</td>
<td>2(6.3)</td>
<td>2(6.3)</td>
<td>4(12.5)</td>
<td>5(15.6)</td>
<td>7(21.9)</td>
<td>7(21.9)</td>
<td>2(6.3)</td>
</tr>
<tr>
<td>OBE implementation cycle 1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Post OBE cycle</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
</tbody>
</table>

Figure 1: Distribution of EE publications according to year based on Table 2
Research Trends before and after OBE implementation

Prior to the implementation of OBE in Malaysia, there had been few research publications on engineering education apart from Alias, Black & Gray (2002), Alias, Black & Gray (2003) and Alias, Gray & Black (2002). With the implementation of OBE as early as 2004 in some Universities interest in engineering education - based on published papers - intensified (Mohd Yusof & Mohamad, 2010). Initially, in the early stages of OBE implementation, the publications were mainly of the “sharing of knowledge” and “sharing of experience” type. This is understandable since sharing of experience was much needed at this stage as academicians, education administrators and managers tried to grasp the implications of the new OBE concept for their own practices. A picture of what went on during this early stage can best be understood from publications by Noor et al. (2009). Publications on research oriented activities emerged naturally at a later stage of the OBE implementation. This was probably due to the need for academicians to identify the impact of OBE on learning and student attributes as well as the need to identify best practices to achieve the desired learning outcomes. Therefore, the publications progressively change from the “sharing of experience” type to work describing research as it is set out in the REES criteria.

Research Focus

The research questions posed by the engineering education researchers reflect research interests of the EE researchers which can be broadly classified into five areas namely, teaching & learning, assessment and evaluation, curriculum design, effect of OBE on student learning and the impact of industrial attachment on graduate attributes.

Teaching and learning

Seven of the research papers reviewed are on teaching and learning and academic success (Akasah & Alias, 2010; Sidhu and Kang, 2010; Mohd Nopiah et al., 2009; Kassim & Mohd Radzuan, 2008; Md Kamaruddin et al., 2008; Alias & Md Saleh, 2007 and Alias & Boon, 2005). The teaching and learning methods investigated include problem-based learning (Mohd Nopiah et al., 2009 and Alias & Md Saleh, 2007); explicit teaching (Alias & Boon, 2005), contextual teaching (Md Kamaruddin, 2008); conflict scenarios (Kassim & Mohd Radzuan, 2008) and whole-to-part approach (Akasah & Alias, 2010). Of great concern was also on how best to integrate technology into engineering teaching and learning (Sidhu & Kang, 2010)

Assessment and evaluation

Irrespective of the approach used, prescribing valid assessments of learning outcomes is always an issue that needs to be reckoned with. In OBE, this issue raises particular concern as successful implementation requires valid assessment of multiple dimensions of learning outcomes. So great is the concern around this issue that it became the research focus of two research Universities, Universiti Teknologi Malaysia and Universiti Kebangsaan Malaysia (Saidfudin, et al. 2010). In addition, another research University,

**Curriculum design**

The implementation of OBE, intensified concern on curriculum design and its impact on the quantity and quality of engineering graduates among engineering educators as indicated by Zaharim, et al., (2007), Osman, (2009), Mustafa, et al., (2008) and Sivapalan (2009). Zaharim et al., (2007), Zaharim, et al., (2009) and Mustafa et al., (2008) were using their research findings for decision- makings in curriculum design and revisions for enhancing graduates' attributes. Still looking at curriculum design although for a different reason, i.e., the declining trend of enrolment rate in engineering programmes, research by Mustafa et al. (2008) involved gathering feedback from multiple groups of stakeholders. A fourth study by Sivapalan, (2009) - a language instructor - was concerned with the English communication skills of engineering graduates and efforts to improve the existing English curriculum through student feedback.

**Effect of OBE on student learning**

With the implementation of OBE, educators were naturally curious whether the desired outcomes were achieved as planned. Therefore studies such as that by Zaharim et al., (2007), were conducted to assess the impact of OBE on learning. Zaharim et al., (2007) compared groups before and after OBE implementations and discovered that students’ performance declined after the OBE implementation as might be expected when students try to cope in the new learning environment pertaining to learning methods, assessment methods and language used in the classroom. Researchers also were interested in getting a better understanding on factors that contribute to learning success. Zaharim, et al., (2006) investigated the association between difficulty levels of questions and grade acquired by students while other researchers looked at the contribution of other factors on learning success such as learning styles and teaching styles (Shafie & Alias 2007), students’ motivation (Paimin, Hadgraft, Prpic & Alias, 2011) and students’ initial career decisions (Alias, & Abu Bakar, 2010). Interestingly, EER is not limited to University degree programmes; pre-engineering degree programmes were also of interest to EE researchers. An example was a study by Husain & Mustapha (2009) on employability skills of polytechnic students. Such a study is also important as some of these students would later on further their studies in engineering degree programmes.

**Industrial attachment and student attributes**

Of great interest to researchers was the impact of industrial attachment/placement on graduate attributes and with that, comes the challenge of how best to assess the impact. Many studies such as those by Omar et al., (2006), Omar et al., (2008), Omar et al., (2009), Abdullah & Zaharim (2008), Zaharim et al., (2007) and Yusoff (2010) adopted a survey design based on questionnaires. Ab Rahman (2009) however used a pre-post survey design to look at the effect of industrial attachment on student attributes while Jamil (2011) conducted a similar study at a later date into the implementation of OBE in 2009. The numerous studies conducted in this area have resulted in accumulated
knowledge on the employability skills required of engineering graduates and this has been synthesized into a framework for employability skills by Zaharim, et al., (2010).

Researchers’ involved

Out of the 33 papers reviewed, 21 (63.6%) of the studies were conducted by engineering core course lecturers. Typically, the same researchers are involved in more than one study. Although the number of researchers is relatively small compared to the pool of researchers in the national engineering field, the number is definitely an improvement from the pre-OBE era when there were effectively only one or two people publishing EER. Thus a top-down directive requiring the implementation of OBE has clearly resulted in a pathway to EER for engineering faculty members where previously EER had not had a place even on the periphery of their research focus.

Research designs

Over 75% of the publications studied refer to the use of the survey research designs based on statistical analysis methods that are relatively simple in nature. This indicates that there is a great focus on describing phenomena. Only five studies used designs that would permit the establishment of causal relationships between variables. It could be that engineering education researchers are not interested in establishing causal relationships or simply lacking in the necessary research skills which is perhaps understandable as expertise in education research methods is still in the process of being acquired.

Support available

Engineering education interest groups were formed in two research Universities, Universiti Kebangsaan Malaysia and Universiti Teknologi Malaysia, both of which set up research groups to focus exclusively on engineering education in their respective Universities. Although these two have contributed a major share of published research there have also been significant contributions from others such as the Universiti Tun Hussein Onn Malaysia (UTHM) which supports EER through its Faculty of Technical Education (FTE): for example, studies by Alias & Boon (2005) and Akasah & Alias (2010) were the result of joint research between researchers from the FTE and the engineering faculty at UTHM, supported by the national Fundamental Research Grant Scheme.

There are no specific research grants for EER but researchers can compete for the available grants from the Ministry of Higher Education namely, Fundamental Research Grant Scheme, Long-term Research Grant Scheme, Exploratory Research Grant Scheme and Prototype Research Grant Scheme.

Discussion

In summary, this article shares the Malaysian experience on how a top-down directive to implement OBE in the engineering sector has opened up a new pathway for EER in Universities. The publications studied have quite a broad focus ranging from teaching and learning to industrial attachments. While the research tends to be of the descriptive type
this may be a consequence of the developing skills among the researchers involved. The volume of research by core course lecturers appears to be directly related to institutional support provided and although the increase in output is notable, most of these studies are done by the same group of researchers and the more prolific researchers come from the more supportive Universities such as UKM that has its own EER Centre and UTM that has a doctorate programme focusing on EER. Although the national EER activity is relatively concentrated and involving a minority of engineering educators, it is certainly increasing and this case study has indeed clearly illustrated the positive role of a top-down directive in promoting EER.

Conclusions

We have described how a decision at ministerial level resulted in a significant flowering in EER activity extending over a range of research categories. Although this process it is probably best considered as the product of a particular national context at a specific moment in the history of its engineering education system, we believe that the case study presented here could provide useful strategic pointers for those in other national contexts where such measures may be contemplated in that it suggests that strong support for top-down change did in this context bring about significant quantitative and qualitative development in engineering education research.

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Creswell, J. (2002), Research Design, Qualitative, Quantitative and Mixed Methods Approaches, Sage, pp 22


**Appendix 1: Publications included in the analysis**


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Hidden barriers to academic staff engaging in Engineering Education Research

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Abstract: At Swinburne University of Technology, the Faculty of Engineering and Industrial Sciences (FEIS) has charged the Engineering and Science Education Research (ESER) group with facilitating change to increase the level of engineering education research within FEIS. This paper reports on the first of a two-stage project, with the research question: How can the barriers to academic staff undertaking engineering education research be usefully conceived and framed to assist academics (and those supporting them) to overcome those barriers? Data was collected using critical reflection and dialogue in reference to the literature. Our findings suggest that barriers can at times be tacit, murky and unnamed—effectively hidden. This paper argues that to support staff to engage in education research and scholarship there is a need to understand and address not only institutional barriers, but also underlying, hidden barriers. This paper proposes an approach to such barriers and describes future research.

Context

Assisting engineering academics to learn how to undertake education research based on their own teaching practice is challenging. At Swinburne University of Technology, the Faculty of Engineering and Industrial Sciences (FEIS), which has approximately 100 academic staff, has charged the Engineering and Science Education Research (ESER) group with facilitating change to: (a) help academic staff develop scholarly approaches to their teaching practices, and (b) increase the level of engineering and science education research within FEIS. To this end, ESER is a traditional research group, but with the added responsibility of providing professional development in education research and in the scholarship of teaching and learning (SoTL) (Mann & Chang 2010; Chang & Mann 2010). Specifically, ESER activities are intended to strengthen teaching practices and hence, improve the student experience. Its activities focus on disseminating good practice within
the Faculty and beyond, as well as broadly supporting the conduct and publication of education research.

While many academic staff may be committed to good teaching, without investigating innovative teaching practices there may be a temptation for academics to reproduce the traditional teaching practices that they were exposed to as students. In addition, the increasing complexities of teaching, together with a lack of support for engineering education research and scholarship at some institutions might seem insurmountable challenges to some academic staff. These challenges may lead a proportion of academic staff to conclude that the more fruitful path in research involves focusing on basic research.

Our work in the area of supporting academics to engage in education research and scholarship has caused us to reflect on the potential barriers to this activity. Some of these 'institutional' barriers are described in terms of a lack of time, lack of institutional support and development, lack of funding, or lack of perceived value, to name but a few (Brodie et al 2011; Haigh et al 2011; McKinney 2002; Wankat et al 2002). However, through reflection on our intensive work in this area, we have come to believe that there are further underlying barriers, which are more murky and tacit than espoused barriers. These 'hidden' barriers, often unacknowledged and therefore unnamed, represent further hindrances to academics' undertaking education research. For example, these may include low confidence in one's research abilities particularly in a new field, reluctance to relinquish control even if only for a short time, and concern over opening one's teaching strategies to external critique. Therefore, we contend that to support staff to engage in education research and scholarship there is a need to understand and address, not only institutional barriers, but also these hidden barriers. Further, we are also interested in additional investigations to see if the same barriers exist to academics who are reluctant to incorporate proven teaching techniques into their teaching practices. At some institutions, it has been argued that participation in engineering education research is the only effective way to motivate engineering academics to adopt new teaching techniques. This paper represents our progress to date and lays the groundwork for future empirical investigations.

Theoretical Frameworks

The project is supported by a number of theoretical frameworks including the Scholarship of Teaching and Learning (SoTL) (Boyer 1990) and critical reflection (Brookfield 1995; Schön 1983). While there is debate around the definition of SoTL, the theoretical literature in this area generally points to three characteristics: (1) inquiry into one's teaching practice, while (2) engaging with the literature, and then (3) publishing that inquiry (Kalish and Stockley, 2009). In tandem with this, the literature around critical reflection, which provides frameworks to uncover influences, assumptions and tacit understandings (Brookfield 1995) assisted our reflections on hidden barriers.
Methodology

This paper reports on a project that explores the following research question:

*How can the barriers to academic staff undertaking engineering education research be usefully conceived and framed to assist academics (and those supporting them) to overcome those barriers?*

The project is being conducted in two stages. In this first stage, the authors generated data through critical reflections, mutual dialogue and engagement with literature. Specifically, the authors first used mutual dialogue to follow Race's (2006) method of generating prompts for reflection (arising out of the research question). The authors then generated written critical reflections (Brookfield 1995; Schön 1983) individually. These reflections were then analysed along with literature to develop a way of conceiving and framing barriers.

Stage two of this project will involve a survey of academic staff perceptions and motivations towards engineering education research. The draft survey (adapted from Haigh et. al. 2011) investigates issues including: personal pre-conditions such as attitudes and existing workload; institutional incentives and disincentives including work culture and values; apparent competition with discipline-based research; and resourcing, such as professional development and education research training, grant money, and support to develop publications. Stage two will also include interviews with selected faculty members, which will explore issues that point to underlying barriers.

Findings

From the analysis of stage one described above, a number of barriers were identified. Importantly, our reflections uncovered that in addition to institutional barriers, further murky and tacit barriers to engaging in education research can lie hidden beneath the surface. Here we report on both institutional and hidden barriers.

Institutional Barriers

In our reflections, we considered that it is not uncommon for academic staff to describe that they don’t have the time to do education research on top of everything else, particularly their basic research and teaching responsibilities. We have also observed a concern that they lack the necessary support to develop their skills in education research or the funding required in starting projects. Further, in our experience, staff have argued in the past that their Faculty or University does not value engineering education research as opposed to their traditional discipline research. While such barriers do exist, it is possible to reduce them. It was found that the activities and support provided by the ESER group reduced these institutional barriers (Chang & Mann, 2010). By providing funding and time allowance to undertake engineering education research projects and an extensive suite of developmental activities, we have found that the institutional barriers for some staff have been lowered to the point that they have started to undertake education research projects. Significant support from Faculty leadership has also
contribution to altering the barrier of that education research is perceived to hold lesser value. However there still remains a group of academics may like to undertake education research, but who are being held back by other barriers.

**Hidden Barriers**

Generally most academic staff care about teaching and care about their students. So why don't more academics engage with education research and scholarship? One reason may be that they don't see the need for education research. Most academics were themselves very capable students in the (sometimes) distant past. These capable students clearly succeeded in their studies to the point where they then went on to successful careers in academia. Because they succeeded in an education system where they were taught in a traditional manner that was centered on the one-way transfer of information (lecturer to student), academics are often under the misconception that good information transfer equates to good learning and teaching. This misconception can be articulated as follows: if the lecture notes are prepared in a logical, thoughtful, coherent and thorough manner and if these notes are delivered via a set of clear and fluent lectures then good learning should occur. If good learning does not occur then the students must be at fault! To reinforce this misconception, academics often gravitate towards setting predictable exams that, for various reasons, encourage shallow learning and recipe-based problem solving. Some students can often perform very well in these exams yet exhibit very poor understanding of key concepts. In essence, they achieve acceptable results in the course by learning how to perform in the exam rather than developing a deep understanding of the key concepts. And if occasionally, performance is under par, there is always a renormalization process to help restore normality. So pass rates are at an acceptable standard, student feedback is generally OK and the academic progresses with their career happy that the lectures they deliver year in and year out are effective. In such a framework, academics often feel that they are extremely effective teachers, and that they do not need to do any research on their learning and teaching (L&T) methods, and that they do not need to be exposed to any new L&T strategies and innovations.

Another barrier centers on "academic memory". After a few years of teaching, academics often forget about how long they spent as a novice in their first university appointment preparing a one-hour lecture for the first time, or how long they spent struggling with a particular concept or idea. Once they have all these ideas clearly explained in their notes (a process that can take considerable time) they can often forget how long they spent struggling over this preparation. As they deliver these lectures year after year and as they become more comfortable with the lecture material and delivery, they assume that students should be able to absorb all these ideas and concepts in real time during the lecture. Again, the conflict with academic memory and the results of education research can result in resistance from academics who genuinely and honestly do not understand why students should be having difficulties.

Another issue has to do with the academics' comfort level. Academics invest a lot of their time and energy in becoming experts in their field, and this also extends to their teaching. Much of the education research data suggest that good learning can occur when academics
make the transformation from lecturers to facilitators. This transformation requires academics to relinquish their authority as the ‘sage on the stage’ and instead transfer a level of control to the students by becoming the ‘guide on the side’ (King, 1993). So the academic’s perception of their role as the expert can limit their ability to be receptive to engaging with education research, which often suggests a very different role. The comfort level also extends to research. Academics generally have spent considerable time and effort in developing expertise in a research discipline. To partition their research to include education research, an area where they probably feel like a novice with a poor grasp of the discipline can be very daunting.

A further comfort level centers on the emotional management required to negotiate ones’ way through the process of education research – from conceptualizing a learning and teaching intervention and drafting an ethics application, to running the intervention and collecting evidence, through to writing and publication. As those attending this conference can attest, this process can be variously frustrating, exciting, tedious, confidence-sapping and exhilarating. In a case where one might find some of these emotional experiences confronting, one might choose not to proceed.

Another barrier centers on the use of an academic’s personal time. For many staff, the immediate goal is to improve their teaching so students learn better. All their energies may be focused on developing and implementing a new L&T strategy or innovation, and doing education research to test the efficacy intervention may be of secondary importance or not important at all. Often staff that make a commitment to concentrate on their teaching rather than research do so because of philosophical, personal, family or lifestyle reasons. It is very hard to convince these staff that the extra work to quantify their teaching innovation into education research is worth the effort. This is also true of ‘teaching and research’ staff who again find it difficult to find the time to convert good teaching into good education research when they have a heavy teaching and discipline research load.

The last barrier has to do with the nature of education research itself. Most academics in engineering or the physical sciences are used to dealing with problems and issues that are deterministic in nature. Although the problems themselves may be complex, there is a sense that a solution can always be found given enough resources and information. Education research usually deals with changing the perceptions of groups of students in an environment which has many uncontrolled variables. This can often be frustrating and unsatisfying for many engineers. Education research may appear to be an emerging, rather than established field to academics new to the area, which again can be unsatisfying for academics who are used to doing discipline research.

**Discussion & Recommendations**

Universities benefit from encouraging academic staff to undertake engineering education research to strengthen student experience. However, various barriers exist. Some are institutional, which can be reduced through support, funding and development activities.
Others are hidden barriers, which can also be reduced by targeted, strategic support activities.

We have observed, through our own practice supporting staff to engage with and develop skills in engineering education research, that an extended program of activities (as opposed to stand-alone workshops, for example) provides staff with opportunities over time to unearth hidden barriers. While workshops have their place, it is through use of a support group, or a community of practice (such as the ESER group), that individuals are able to quietly unearth their hidden barriers, through dialogue with others and also by observing colleagues who are positive role models for overcoming similar barriers. It is through an extended and holistic approach, such as a support group, that hidden barriers may be addressed. Therefore, it is our recommendation that strategic planning to support staff to develop in engineering education research consider extended, holistic strategies to address hidden barriers.

Our future research in this project will augment this initial stage by surveying and interviewing academic staff on their perceptions and motivations towards engineering education, which will explore issues that point to underlying barriers.

References


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Analysis of Trends in United States National Science Foundation Funding for Engineering Education: 1990-2010

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Abstract: We present quantitative data and analysis of U.S. National Science Foundation funding for engineering education. We identified 6500 grants awarded since 1990, and coded 1608 as focusing on engineering. The average annual funding level for engineering education over the past ten years has been $30.7 million and has come primarily from Engineering Education and Centers (EEC, 43%) and CCLI-TUES (42%). Engineering education is also funded by the Discovery Research K-12 program (10%) and REESE-ROLE (5%). Overall funding has increased over time, while average award size has decreased. At REES, we hope to develop contacts and resources to help us understand the situation in other countries and regions, perhaps to lead to an international comparative analysis of engineering education funding.

Introduction

It has been argued that U.S. engineering education researchers have the luxury of abundant federal funding which far exceeds that of other countries. The relatively long history and high level of funding means that a range of emphases, strategies and foci have been applied and can be quantified. We begin in 1990 when large-scale, multi-institution coalitions for the reform of engineering education, eventually funded for a total of $164 million, were first established. For each program, quantitative and qualitative data regarding the level and focus of engineering education-related funding are presented. These data are supplemented by interviews with long-time program officers providing additional historical context for trends in engineering education funding. Our research questions are:

1. Which NSF programs have historically funded engineering education?
2. How much NSF funding has been available for engineering education?
3. What is the relative distribution of NSF funding for K-12, undergraduate and graduate engineering education?
4. What, if any, are the trends over time?
Theoretical Perspective

This paper takes a basic science policy perspective which recognizes that science is political (Guston & Sarewitz, 2006). As much as scientists and engineers wish to rely on ideals of objectivity and unbiased peer review, the process of selecting which competitive proposals to fund is subject to individual judgment and assumptions about the mechanisms for solving problems such as diminished engineering student recruitment, retention and diversity. This is particularly true when evaluation data are lacking. At the National Science Foundation, approximately half the program staff are temporary "rotators" on 1-4 year assignments from their home academic institutions; this is by design to ensure that program officers are active researchers in their fields, but it also impacts program directions.

Methods

The U.S. National Science Foundation is a federal agency created in 1950 with the mission "to promote progress of science; to advance the national health, prosperity, and welfare; to secure the national defense." Presently, the total annual budget is nearly $7 billion. Its primary mechanism of funding is limited-term grants (10,000 new ones per year out of 40,000 proposals submitted) with an average duration of three years. NSF supports approximately 20 percent of all federally funded basic research at U.S. colleges and universities. NSF is organized into 7 directorates roughly aligned to academic disciplines. Engineering education grants are awarded by both the Directorate for Engineering (ENG) and the Directorate for Education and Human Resources (EHR). EHR funds education activities across all STEM disciplines; most funding programs target all of STEM but include awards for engineering education. In contrast, all education awards by ENG are engineering education-related. Table 1 presents relevant characteristics of the four programs selected for analysis. We also considered The Teacher Professional Continuum program (now part of DR K-12), which funded models of professional development in engineering and technology education, but found no unique awards since 1990 that were not cofunded with IMD or DR K-12.
Table 1. National Science Foundation Engineering Education-related Funding Programs Analyzed for this Paper. ENG=Directorate for Engineering, EHR=Directorate for Education and Human Resources.

<table>
<thead>
<tr>
<th>Program</th>
<th>Years Funded</th>
<th>Goal (Most Recent RFP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Education Research funded by the Division of Engineering Education and Centers (EEC) in ENG</td>
<td>Continuously during sampling period (1990-2010) and ongoing</td>
<td>Engineering education research, advancing knowledge of engineering learning (PD 10-1340)</td>
</tr>
<tr>
<td>Course, Curriculum and Laboratory Improvement (CCLI), now Transforming Undergraduate Education in STEM (TUES) in EHR</td>
<td>CCLI: 2000-2010 TUES: 2010-ongoing</td>
<td>Improvement in STEM education for all undergraduate students (NSF 10-544)</td>
</tr>
</tbody>
</table>

We downloaded abstracts and other award information from the public awards database at [www.nsf.gov/awardsearch](http://www.nsf.gov/awardsearch). For all but EEC, we used the titles and abstracts to determine which awards were engineering-related. Engineering as part of a general STEM focus was excluded, but engineering technology, technology literacy projects describing engineering, and engineering applications of math and science were included. Many awards were cofunded between the different programs studied here and others. To remove duplicates from the database, each award was categorized by its home "NSF Organization," which is unique for most of the programs. Descriptive quantitative analyses were run, and these were shared with long-time program officers in these programs for comment. Award abstract text and program solicitations were also used to understand foci and trends.

**NSF Programs not included in this analysis**

A number of other programs that could be included in an expanded analysis were cited by NSF program officers. STEM Talent Expansion Program (in EHR) seeks to increase the number of students earning baccalaureate degrees in STEM disciplines. It funds Type I awards to implement efforts at an institution and Type II awards to research recruitment and retention. In 2011, NSF will also award a $10 million STEP Center in the area of engineering student innovation, cofunded by ENG. Advanced Technology Education (EHR) is the parallel program to CCLI and TUES, focusing on STEM in two-year colleges, including engineering technology and engineering sciences. The ATE program focuses on the education of science and engineering technicians at the two year college level. Innovative Technology Experiences for Students and Teachers is a K-12 program which funds some engineering projects. The Informal Science Education program funds exhibits, TV shows, and large format films in engineering. Computer Science is part of the Directorate for Computer & Information Science & Engineering, and related computing education programs have been funded through this directorate for many years. Other traditional science funding programs have strong
education goals. Faculty Early Career Development Program (CAREER) is an early career award to untenured engineering and science faculty members; all awardees are required to integrate research and education in some way. This is a very prestigious award, a few of which each year are selected for Presidential Early Career Awards for Scientists and Engineers (PECASE). CAREER grants have been awarded to engineering education researchers since 1999 and PECASE awards since 2007. Centers (Engineering Research Centers, Nanoscale Science and Engineering Centers, Materials Research Science & Engineering Centers, Science of Learning Centers and Science & Technology Centers) have significant education missions which often result in focused K-12 outreach as well as new graduate and undergraduate courses.

Findings

In addition to many smaller awards, a few very large engineering education coalitions and centers have been funded since 1990. Centers and coalitions are described first below, followed by quantitative analyses and trends over time, which exclude large centers and coalitions because they skew total and average award amounts.

Centers and Coalitions

From 1990-2005, the Engineering Education and Centers Division of NSF funded eight engineering education coalitions of over 40 colleges and universities ($13-15 million each) (Froyd, 2005). These coalitions "were intended to catalyze systemic change across the engineering education community by developing and demonstrating the efficacy of new curricular models" (Froyd, 2002, p. 1). Much has been written about the engineering education coalitions, including their contributions (in the U.S.) to reforming engineering education practices (Froyd, 2005), new ABET accreditation criteria, and developing a new generation of engineering education researchers (Borrego et al., 2007), laying the foundation for increased assessment and more scholarly engineering education research (Borrego, 2007).

Engineering Research Centers usually focus on cutting-edge research within and across traditional engineering disciplines, but the The Vanderbilt-Northwestern-Texas-Harvard/MIT (VanTH) Engineering Research Center for Bioengineering Educational Technologies was funded in 1999 at $21 million with a focus on biomedical engineering education. Three Centers for Learning and Teaching ($10-16M) were awarded by the Directorate for Education and Human Resources in area related to engineering: Center for the Advancement of Engineering Education (2003, primarily undergraduate, led by University of Washington), National Center for Engineering and Technology Education (2004, primarily K-12, led by Utah State University), and NCLT: A Center to Develop Nanoscale Science and Engineering Educators with Leadership Capabilities (2004, K-20, led by Northwestern University). These large centers certainly play a major role in development of engineering education knowledge, capacity and resources, particularly as most are ending and preparing final reports and dissemination activities at national conferences. As with coalitions, it may be several years before their full impact can be articulated and measured.
Table 2. Overview of 2000-2010 Results.

<table>
<thead>
<tr>
<th>Program</th>
<th>Student level</th>
<th>Total engineering funding</th>
<th>Number of awards</th>
<th>Average award size</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEC</td>
<td>Primarily undergrad</td>
<td>$138M</td>
<td>525</td>
<td>$318,392</td>
</tr>
<tr>
<td>CCLI-TUES</td>
<td>Undergraduate</td>
<td>$135M</td>
<td>794</td>
<td>$171,473</td>
</tr>
<tr>
<td>IMD-DR K12</td>
<td>K-12</td>
<td>$31M</td>
<td>26</td>
<td>$1,426,814</td>
</tr>
<tr>
<td>ROLE-REESE</td>
<td>K-12, undergrad and graduate</td>
<td>$17M</td>
<td>30</td>
<td>$584,856</td>
</tr>
</tbody>
</table>

Quantitative Results

We identified 6500 grants awarded since 1990 from these programs, and coded 1608 as focusing on engineering. Since two programs run 1990-2010 and two others run 2000-2010, most comparisons are from 2000-2010. Table 2 summarizes the results. The average annual funding level for engineering education over the past ten years has been $30.7 million. Approximately one-third of these awards were cofunded by multiple programs, including but not limited to those analyzed here.

Figure 1 better illustrates the relative contributions of the various programs. Engineering Education and Centers and the CCLI-TUES program account for 96% of the engineering education awards over the past decade. However, the average award size in the other two programs is much higher, so EEC and CCLI-TUES account for 85% of the budget spent on engineering education. These findings are influenced to a large extent by the high number of relatively small awards made through the CCLI-TUES program $100,000-$150,000 focused on improving engineering education in a specific course. (This program also awards a small number of medium awards up to $600,000 and large awards up to $5 million.) Average success rates for proposals submitted to the programs from 2005-2010 are comparable: EEC = 28%, CCLI-TUES = 22%, ROLE-REESE = 23%, and IMD-DR K12 = 21% (percentages for EHR programs are for all STEM proposals, not just engineering).

Figure 1: 2000-2010 NSF Funding for Engineering Education. (a) Number of Awards. (b) Dollar amounts
Trends over Time

Figure 2a is a plot of the total engineering education funding from all four programs over time. Although there is much fluctuation from one year to another, there is a clear upward trend in the total amount of engineering education funding. However, over the same time period, average award size (Figure 2b) has been declining. From 2000-2010, the overall National Science Foundation annual budget has been steadily increasing from $3.9 billion to just under $7 billion. As a percentage of the overall NSF budget, engineering education funding in these four programs has fluctuated between a low of 0.33% in 2009 and a high of 0.53% in 2001 and 2006.

In each of the four programs, total funding for engineering education features an upward trend over time, with EEC and CCLI-TUES having the steepest slopes. On the other hand, average award size for IMD-DR K12 and ROLE-REESE is increasing with the steepest slopes. Average award size for CCLI-TUES is also increasing, while average size for Engineering Education and Centers award size is decreasing. (Since EEC accounts for the largest proportion of both total funding and total awards, its trend dominates.) However, we note that the rate of decrease in EEC average award size is less from 2000-2010 than it was from 1990-2000.
Discussion

These results demonstrate that U.S. engineering education innovators and researchers have a wide range of NSF funding opportunities available to them, from large centers to small seed grants to initiate new projects. Other federal agencies, such as NASA and the Department of Defense, also fund engineering-related education interventions, but NSF views its unique role as providing the research base and initial translation to practice for cutting-edge STEM education.

These results focus on long-term trends because many values fluctuate from year to year. Specific funding initiatives which strongly influenced annual totals and trends over time include the engineering education coalitions, large research and education centers, nanotechnology and the 2009 economic stimulus package.

The two primary engineering education programs (EEC and CCLI-TUES) focus on the undergraduate level, CCLI-TUES by virtue of its location in the Division of Undergraduate Education. Similarly, IMD-DR K-12 focuses on K-12 and was originally part of the Division on Elementary, Secondary and Informal Education. That division was merged in 2005 with ROLE-REESE's home to form the Division for Research on Learning in Formal and Informal Settings (DRL). This merger strengthens the connections between K-12 science and math researchers and learning scientists, but may also serve as a disadvantage to engineering education scholars who work in a newer field that is less engaged with learning sciences and more focused on implications for practice. Program officers estimate that the success rate for engineering REESE proposals is lower than the overall rate but increasing.

While the EHR programs have remained relatively stable since 1990 (noting name changes to reflect shifts in focus), ENG programs (in EEC) have changed every few years. A strong relationship between educational research and teaching practice was evident since Combined Research and Curriculum Development program (1996-2000), but the language has been refined through solicitations for Department-Level Reform (2002-2005), Innovations in Engineering Education, Curriculum and Infrastructure (2008-2010) and Research Initiation Grants in Engineering Education and Engineering Education Research (2011-ongoing). The current program description for Engineering Education Research clearly articulates expectations for research and its potential impacts on practice:

An ideal engineering education research project addresses the iterative cycle in which research questions that advance understanding are informed by practice and the results of research are, in turn, translated into practice. In discussing how the planned work advances understanding, competitive proposals will ground the proposed work both in a theoretical framework and relevant prior work, describe how the research advances knowledge of how engineering students learn, and discuss how the research results are broadly generalizable and transferable. In discussing how research can be translated to practice, competitive proposals take the point of view of a potential user of the educational innovation, describing how the research results can affect the practice or process of educating engineers, improve the infrastructure for engineering education, or build networks and
capacity for engineering education research for example. (National Science Foundation, 2010)

Conclusion, Recommendations, Future Work

Solicitations include increasingly refined language about research (including applications of research) in engineering education. We also see evidence of a trend towards increasing focus on translating research to practice and encouraging wide adoption/application of the results. EEC has increasingly focused on research with a quality criterion of applicability to practice. During this time, CCLI funded faculty members seeking to apply the results of educational research in their engineering and science classrooms, and in 2000, added a research and assessment track (which has funded 19 engineering education research/assessment grants). In recent years, however, both are focusing increasingly on the gap between research and practice. The recently archived Innovations in Engineering Education, Curriculum, and Infrastructure (IEECI) solicitation from EEC included a research track for “how to more effectively translate successes in engineering education research into widespread practice.” And the 2012 federal budget request includes a new program to be run out of the same division as CCLI-TUES to “[move] improved undergraduate STEM education practices to scale.”

References


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A possible resistive electrical circuits learning pathway for engineering students

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Abstract: This paper proposes a learning pathway consisting of four different stages of electrical circuit understanding levels. This learning pathway is based on literature and on information collected along this research work. The information was taken from students' tests in the course fundamentals of electric circuits in 2011 and from the literature related with students' misconceptions.

Introduction – overall layout

Many engineering specialties include, in addition of an electrical physics course, a course in basic electrical circuits, which further serves as foundation for the career.

Literature also presents extensive research on the meaning of learning some basic concepts of circuits and, in particular, on incomplete and often erroneous conceptions that students have (Campos, 2009); errors that remain even after taking university courses on the subject (Periago & Bohigas, 2005; Smith, 2009). Likewise, specialized literature offers different types of thoughts regarding the understanding that students have on basic concepts of electrical circuits (Gonzalez, 2006).

This research attempts to answer the following question: is there a path for learning that could characterize the evolution of conceptual understanding that engineering students have about resistive electric circuits? Taking into account the research in the didactic field on this subject, it is expected that we will be able to propose in the near future appropriate teaching and learning strategies in the context of didactic of engineering (Getty, 2009).

This paper proposes a learning pathway consisting of four different stages ranging from local thinking to holistic thinking regarding resistive circuits. The proposal of those stages is based on literature and on information collected along this research work, and on the use of an evidence-based evaluation framework using both multiple-choice tests as well as performance tests.

The research is conducted within the framework of a basic course dealing with fundamentals of electrical circuits during the years 2010 and 2011, wherein two teaching strategies are used: inquiry-based learning and learning focused on conceptual change.
Electrical circuit misconceptions

The understanding of electrical circuits at the level of high school and college has been the subject of several investigations. Indeed courses seem to focus on the manipulation of rules and equations in order to solve quantitative problems without developing a coherent conceptual framework for scientific theories. Courses also seem to introduce students to solve exercises following procedures, allowing the student to answer correctly even without having the knowledge of the rules that govern the circuit.

Some of the researches concerning the way in which students acquire knowledge show that in the learning-teaching process the students come to the classroom with practical and intuitive knowledge concerning laws and physical phenomenon and that they explain how things work in the real world based on this type of knowledge.

The research shows conceptual schemes about circuits and electricity (Closset, 1983; Furió & Guisasola, 1999; Hierrezuelo & Montero, 1988; Picciarelli, Di Gennaro, Stella, & Conte, 1991; Pontes & De Pro, 2001; Shipstone, 1984; Varela, Manrique, & Favigres, 1988). This conceptual framework has recollected preconceptions of everyday life experiences that students take as their own and that are not always correct.

According to those studies, and on what they all agree, the main preconceptions are (Gonzalez, 2006):

1. Difficulties to distinguish and use terms like: potential difference, voltage, current, etc.
2. The current is thought as a fluid material.
3. They do not see the necessity for the circuit to be closed for the existence of an electrical current.
4. They tend to use sequential reasoning. For example, they think that the current becomes weakened or exhausted as it passes through a circuit or think there can only be charges after the circuit element changes.
5. They tend to interpret the voltage as a property of the current, instead of considering the current to be a consequence of the difference in potential between two points of a conductor.
6. The students have difficulties in interpreting the graphical representations of the circuits. They are not able of associating the real circuit with their graphical representations, though it is a question of simple assemblies.

The investigations also showed that when making changes to a circuit students fail to understand that changes affect all the circuit and have an effect on voltages and currents.

This paper, delve into the so-called local and sequential reasoning described as:

In Local reasoning the students focus their attention upon one point in the circuit. A change in the circuit is thought on as only affecting the current and/or the voltage in the point where the change is made (Bernhard & Cartestensen, 2002). In Sequential reasoning if something is changed in the circuit this is thought on as only affecting current and/or...
voltages in elements coming after the place where the change was made, and not before (Bernhard & Cartestensen, 2002).

**Proposed learning path**

Next figure resume typical moments in the electrical circuit understanding:

![Figure 1: Electrical circuit evolution of the student's thinking](image)

**Evaluation tools**

The course was structured in three main modules: static circuits, dynamic circuits and frequency response in circuits. This experiment was focused only in static circuits.

A test was taken by students at the beginning and at the end of the module. This test is based on an evaluation matrix gathering great affirmations covering the entire module. These affirmations are split into several pieces of evidence which are turned into tasks that the questions evaluate. The evaluation matrix is based on Evidence Centered Design of assessment (ECD) - a design methodology for the design of educational assessments in terms of evidentiary arguments - (Feng, Hansen, & Zapata-Rivera, 2009).

The initial test (Pretest) has 28 questions virtually presented to the students that assessed various tasks that are part of the local and sequential reasoning. The Final Test (PostTest) has 23 similar or equivalent tasks that assessed the Pretest. 43 students presented both test (pre and post).

**Results**

![Figure 2: Reasoning Student progress between tests](image)
At the beginning of the course most of the students presented a Local reasoning to analyse electrical circuits. At the end of the course, only one student remained with a local reasoning. In fact, most of students that initially presented local reasoning, reached a level of sequencial reasoning by the end of the course. The students that presented sequencial reasoning at the beginning of the course obtained integral/holistic reasoning by the end of it. The test didn’t allow to discriminate between integral and holistic reasoning. Finally, the next figure illustrate de improvement in electrical circuit reasoning (1: local; 2: sequential; 3: integral/holistic). This figure shows that the intended educational strategy allows approaching the integral/holistic reasoning despite the initial result. Some students, however, seem to reduce its performance. This result could be associated to a bad conception of the test for measuring integral/holistic reasoning.

![Figure 3: Student gain between tests](image)

**Conclusions**

The results seem to confirm the learning pathway proposed in this article. The pathway begins with a majority of students in local reasoning which are able to achieve a sequential reasoning at the PostTest. Furthermore students who used sequential reasoning in the PreTest, tend to use integral / holistic reasoning development in the Post Test.

In general, students advanced in their conceptions of static electric circuits through classroom activities and teaching strategies used in the course. However, a detailed analysis of their answers shows that some students remain with very basic misconceptions.

Further research could be conducted in order to discriminate between integral and holistic reasoning.

**References**


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Evaluating tutor training for online PBL teamwork courses in first year engineering

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Abstract: The use of Problem-based Learning and other collaborative pedagogies in undergraduate engineering courses is recommended by a plethora of learning theory and research on educational best-practice, particularly for Applied Sciences such as Medicine and Engineering. One barrier to implementing and sustaining these curricular and pedagogical approaches lies in the development of the appropriate knowledge and skills and a consistent and appropriate approach in the teaching team. A significant change from the traditional pedagogies employed by tutors and the training of tutors is required, if PBL and similar methods are to be effective in delivering their numerous affordances, especially in asynchronous online environments for distance learning. This paper describes the development of a strategy to train engineering tutors in online PBL facilitation, and the evaluation framework used to assess the effectiveness of this training. Results of the evaluation of training and subsequent behavioural changes of the tutors are given. The evaluation revealed a variance between the message of the training and subsequent practice. Recommendations are made about the need for ongoing tutor development and support, and the necessity of evaluation in the implementation of PBL pedagogies

Introduction

Although the theoretical bases of PBL and other collaborative and student centred pedagogies are well established in educational literature (Litzinger et al. 2011) the evaluation of their implementation within universities should be understood as a separate concern and subject of study for tertiary educators. Implementation involves a number of specific considerations which can be understood by examining case sites such as our institution. The Engineering Problem Solving Strand is a core strand of four courses offered in all of the Engineering and Surveying Faculty's undergraduate programs
(Bachelor of Engineering, Bachelor of Technology and Associate Degree programs across all majors). The courses use a Problem Based Learning paradigm, in which students work in teams to meet a wide range of course objectives. These are primarily concerned with the skills involved in several key graduate attributes, such as teamwork, communication, and problem solving. Many students access these courses externally, and therefore engage in their learning in an online environment. This adds another dimension to the skills required of PBL teachers and the requirements for PBL training programs.

Whilst tutor development resources and workshops in PBL have been in place for some time at [our institution], until recently they have been run on an ad hoc basis. They included no formal mechanism to monitor ongoing tutor requirements, or to evaluate either the workshops or the courses themselves to ensure that the implementation of PBL methods has been successful and appropriate. There was also no opportunity to capture valuable information about how the PBL approach was being played out within the constraints of the online environment and the issues that this might raise. PBL courses, whether online or proximal, require high levels of maintenance if they are to deliver their promised benefits year after year. In developing tutor training and resources it became clear that some of the pressure of this maintenance could be relieved by instituting ongoing monitoring and evaluation structures. These structures also have the capacity to optimise the use of PBL pedagogy by providing information to feedback into an ongoing process of calibration of the PBL approach.

The role of the tutor in PBL

PBL requires that tutors take a particular approach: to facilitate the learning. This requirement derives from the nature of PBL: a form of learning in which students collaboratively construct and elaborate on an integrated understanding of the subject matter, based on their prior skills and knowledge and the exploration of a relevant and rich problem-based context (Savery & Duffy 1995). Problems presented in the PBL context are ill-structured, with no single solution or solution path; they are designed to simulate real world contexts through their richness and complexity. Thus, students are provided with the opportunity to develop authentic and transferable skills in problem solving, critical thinking and self-directed learning (Das et al. 2002; Hmelo-Silver & Barrows 2006; Sobral 1997). Learning in PBL should be driven by deductive processes such as hypothesising, research, investigation and discussion. This deduction is directed by the students themselves as learning and ideas are elaborated, tested, and ultimately deepened by group discussions among students (Dahlgren, Castensson & Dahlgren 1998). The role of the teacher is to guide and support the learning so that the necessary deductive processes are enabled (Collins, Brown & Newman 1989). As such, tutors in PBL should not simply disseminate information and answers to students, but encourage students to negotiate meaning. Tutors provide feedback, and seek to stimulate student interest in learning (Dolmans et al. 2002). They do this by asking timely questions, by drawing students’ attention to matters of relevance and importance, and by encouraging students to summarise and reflect on what they know. The tutor’s role is that of a facilitator.
The effectiveness with which tutors fulfil their role is influenced by the preconceptions that they bring to the learning environment about the nature of effective teaching and learning (De Grave et al. 1999). Rando and Menges, (1991) propose that individuals’ personal theories of teaching and learning are often implicit and inaccurate. Differences in pedagogical approaches may be broadly categorised into two main models: „learning facilitation” and „knowledge transmission” (De Grave et al. 1999). Lecturers who see their role as transmitting knowledge are more focused on the content of the learning than on the processes that are required for it to take place (Dolmans et al. 2002). This represents a significant challenge for PBL tutor training. Many participants in the workshops continually expressed concerns about how best to get information across to students, thus revealing their implicit acceptance of the transmission model. Other tutors more accurately saw their role as „facilitating”: focussing on the processes they wish their students to engage in, in order to develop and demonstrate the requisite skills and knowledge surrounding the subject matter being learned. These different approaches to teaching provide a hypothetical explanation for differing levels of effectiveness among PBL tutors (Dahlgren, Castensson & Dahlgren 1998; De Grave et al. 1999). This difference, along with other concerns, was the focus of the evaluation of tutor training for the PBL courses.

The tutor training program

The difference between the role of the PBL tutor and traditional beliefs about teaching creates a significant potential barrier to the successful implementation of authentic PBL pedagogies. The PBL tutor training program undertaken at [our institution] was targeted at addressing this. The training program is discussed in detail in Brodie and Jolly (2010). However, the key point of the training was that it was run using a PBL approach. Whilst operating as learners in a PBL environment, the participating tutors explicitly examined both the theoretical foundation and pedagogical practice of PBL. This provided an opportunity to address the fundamental beliefs which underpinned their teaching approaches.

The clear message of the training program was the need to redefine the tutor’s role from instruction/transmission to facilitation. It was hoped that this day of training challenged tutors to view their practice as skills-based, with a need for continual development and self-reflection on performance. Although a participant survey of the training was carried out at the end of the program, providing data on how well the facilitation message was understood and accepted, the true outcomes of the training could only be empirically demonstrated by examining the consequent facilitation practices of participating tutors.

Monitoring and evaluation

Following the lead of major development organisations such as the World Bank and government departments, in a program logic approach was taken to the monitoring and evaluation of this program of tutor training (University of Wisconsin 2010). The approach identifies all relevant inputs, outputs, outcomes and impacts so as to set out clearly what it is that needs to be monitored and evaluated (Brodie & Jolly 2010; Markiewicz 2010; Perla & Carigio 2009). Brodie and Jolly (2010) discuss in detail the matrix was that used in
planning monitoring activities, and how it set out what the program was designed to achieve and how it was to achieve it. It centred on evaluation questions such as the following:

- Did the training model the target behaviour?
- Were the models provided suitable for the job?
- Was the facilitation message well understood?
- Was the training effective in demonstrating PBL?
- How often during semester did tutors draw on the training?
- Is the training adaptable to experienced tutors?

Data Collection and Analysis

One of the goals of the project was to evaluate how effective the training initiative had been for promoting positive PBL facilitation techniques among tutors, and to adjust the training and tutor support, if necessary. Deciding whether the training had worked was primarily concerned with determining if the facilitation versus transmission had been understood, accepted and if it was translating to tutors' practice. The Program Logic analysis that was undertaken (University of Wisconsin 2010) resulted in the following data collection strategy (Table 1) but this paper focuses on the analysis of online discussion lists.

<table>
<thead>
<tr>
<th>Data Collection</th>
<th>Timing</th>
<th>Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exit surveys</td>
<td>Training day</td>
<td>Immediate to course controller</td>
</tr>
<tr>
<td>Analysis of discussion lists (online asynchronous forums) – tutor behaviour</td>
<td>Scan Half way through semester</td>
<td>Feedback to tutors</td>
</tr>
<tr>
<td>Analysis of discussion lists (online asynchronous forums) – student behaviour</td>
<td>End of semester</td>
<td>Add to data log – annual report</td>
</tr>
<tr>
<td>Peer discussion</td>
<td>End of semester</td>
<td>Feedback to tutors</td>
</tr>
<tr>
<td>Course reflection</td>
<td>End of semester</td>
<td>Feedback to tutors</td>
</tr>
<tr>
<td>Library list</td>
<td>End of semester</td>
<td>Add to data log – annual report</td>
</tr>
</tbody>
</table>

On completing the workshop, participants were asked to fill out an evaluation form using a simple Likert scale to answer a number of questions. This was used to determine if the tutors considered the training effective and useful.

Following the training workshop, a number of tutors were interviewed to gain deeper insight into the central evaluation questions. With little variation, the data from these interviews also indicated that the key message of the training had been communicated, understood and accepted. The interviewed tutors could clearly articulate the nature and importance of the PBL facilitation techniques that were communicated in the workshop.

In order to examine how the message of the training translated to the facilitation techniques of participating tutors, further analysis of was undertaken. This was conducted by means of a content analysis of each tutor’s interaction with students on the online
discussion forums for the course. Discussion forums constituted the main means by which tutors were interacting with their student teams and intervening in their learning. Each tutor was responsible for 4-6 student workgroups.

In order to restrict the volume of data to be analysed, a number of filters were applied to the data collection. Only threads with greater than six posts were included for analysis, unless there was insufficient data from other threads for a given workgroup. In analyzing the data, tutors' interactions with students were coded according to seven observed nodes of interaction type. These types along with corresponding examples are listed in Table 2.

**Results**

The evaluation questionnaire results are shown in Figure 1. A number of questions asked them to rate the workshop on a scale of one to four, one being to a considerable extent, and four being not at all. Ratings were provided by participants for each of the following about the workshop. The workshop:

- helped clarify my understandings of group learning
- helped clarify the role of the tutor
- motivated me to focus on learning processes not content
- gave me strategies for focusing on learning processes

The results in Figure 1 suggest that the training was understood and considered effective by the participants in achieving each of these objectives.

Table 2 describes the range of facilitation techniques that were observed in the forum data. According to the theory of PBL, questioning and prompting learning behaviours are the most appropriate and effective of these tutor behaviours (Hmelo-Silver & Barrows, 2006). Confirmation, pointing out problems, questioning, recognition and reminders are also appropriate, as they do not contradict the tenets of PBL and they support effective learning processes, especially when used in combination with questioning and prompting learning behaviours (Hmelo-Silver & Barrows, 2006). Prompting and providing content, on the other hand are less appropriate, as they do not actively encourage student self-directed learning. To give an idea of how each of these types of facilitation appeared in practice, Table 2 outlines a description and some examples of each (taken from a variety of tutors).

Figure 2 summarises the overall results for facilitation technique for each tutor for whom data was available.
Figure 1: Exit survey results

Figure 2: Results of Facilitation Technique
Table 2: Interaction coding descriptions and examples

<table>
<thead>
<tr>
<th>Interaction Type</th>
<th>Description of Interaction Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confirmation</td>
<td>the tutor confirms a point from the discussion on the forum</td>
<td>“You have it exactly right. For the best marks in almost every assessment criteria you should be endeavouring to demonstrate (not just theorise) this principle.”</td>
</tr>
<tr>
<td>Pointing out problems</td>
<td>the tutor points out a problem or potential pitfall with the team’s work or procedures</td>
<td>“I get a lot of reports submitted where it’s obvious that one person has come up with the design objectives and another has done the evaluation strategy, with barely any relationship between the two.”</td>
</tr>
<tr>
<td>Prompting content</td>
<td>the tutor prompts students to include some form of content in their report or assessment</td>
<td>“One other thing that I would advise is to include your Code of Conduct within an appendix and refer to it within the TE&amp;R.”</td>
</tr>
<tr>
<td>Prompting learning behaviours</td>
<td>the tutor makes a post which encourages a certain learning behaviour or task to be performed by students</td>
<td>“You should see your lack of knowledge (or inability to contribute further) as an opportunity to do steps 3 and 4 of the Problem Based Learning process.”</td>
</tr>
<tr>
<td>Providing content</td>
<td>the tutor gives students content to include in their report or assessment</td>
<td>“Ideas such as planting native vegetation on the W-WSW side of the shed to protect it from the hot sun in the afternoon should be part of your strategy.”</td>
</tr>
<tr>
<td>Questioning</td>
<td>the tutor asks students a question about their learning or processes</td>
<td>“Do these evaluation questions stem from your background research and design objectives?”</td>
</tr>
<tr>
<td>Recognition</td>
<td>the tutor provides a positive acknowledgement that student work or processes are effective or appropriate</td>
<td>“Having the two different lists is a good idea as it gives you a certain amount of flexibility for the next report.”</td>
</tr>
<tr>
<td>Reminders</td>
<td>the tutor includes a reminder regarding a task to be performed, content to be included or a procedure to be followed</td>
<td>“I would like you all to re-read my opening post in this thread.”</td>
</tr>
</tbody>
</table>

Tutor A provided the best exemplar for PBL facilitation, by frequently displaying the desired facilitation techniques of prompting learning behaviours, questioning, pointing out problems and recognition. This tutor’s discussion forums yielded a high number of instances of facilitation compared to other tutors, suggesting that this tutor was frequently, consistently and effectively involved in their groups’ learning processes, without unduly directing them. On the other hand, Tutor B demonstrated a high number of interactions of either prompting or providing content for students. This was somewhat balanced by the presence of some interactions which demonstrated positive PBL facilitation techniques, such as prompting learning behaviours or pointing out problems. Nevertheless, the data from this tutor suggest that the facilitation versus transmission message of the training was only partially being applied in practice. A less encouraging example, Tutor G was not seen to have any interaction with the students and their learning at all, and, as such, the training message in this instance was unsuccessful.

In comparing this data with the results from in-depth interviews with selected tutors, and broad exit data obtained following the workshops, it was found that although the facilitation versus transmission message of PBL was effectively communicated, accepted and understood by participating tutors, key facilitation behaviours did not consistently transfer to instances of actual practice in the online environment. As such, the evaluation process uncovered a significant disparity between tutors’ understanding and acceptance of the training program, and their ability to apply it during facilitation.

Conclusions

Despite the theoretical basis for the design of the PBL tutor training program, these results suggest that one-off training sessions alone are not sufficient to ensure that the
implementation of PBL pedagogies is optimised. Whilst the training provided did promote the required pedagogies, this was not enough to ensure that the message that was communicated could be consistently put into practice by participating tutors. Training programs may need to be combined with a number of ongoing, Faculty-level supporting strategies in order to be optimally effective. For example, although the training attempted to address the fundamental beliefs and approaches of the participating tutor (the primary barrier to successful implementation), the approach that the training promoted was, in some instances, highly divergent from participating tutors' habits and preconceptions about teaching and learning. For each tutor's response to the message of the training to be enduring, the tutor development program needs to be embedded and ongoing.

Admittedly, the above evaluation was not exhaustive, and is limited in what it can empirically demonstrate about the effect of the training. More sophisticated measures would need to be implemented for a deeper insight into the question "what works for whom under what circumstances?" when it comes to promoting optimal PBL facilitation and pedagogy. For example, this evaluation does not take into account the effect of aspects such as course design and student attributes and behaviours on facilitation techniques. However, this evaluation does demonstrate that tutor training sessions cannot stand alone. It is the difference between the exit data and the evaluation results that indicate the need for ongoing support and periodic evaluation. As important in the process of PBL implementation is the monitoring, evaluation and, if necessary, revision of PBL practices. A systematic approach to the evaluation of PBL implementation, such as the program logic approach described above, is necessary if insights such as the ones discussed above are to be available to the Faculties attempting to implement PBL pedagogies. It is through these methods that the Faculty can learn how to support their tutors in fulfilling their role. Without the information and feedback from these processes, along with continuous support and opportunity for skill development, PBL and other cooperative pedagogies are likely to be unsustainable, and may lead to reduced learning outcomes in collaborative learning environments.

References


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Measuring the influence of Cooperative Learning and Project Based Learning on problem solving skill

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Abstract: The aim of this study is to evaluate the effects obtained after applying two active learning methodologies (cooperative learning and project based learning) to the achievement of the competence problem solving. This study was carried out at the Technical University of Madrid, where these methodologies were applied to two Operating Systems courses. The first hypothesis tested was whether the implementation of active learning methodologies favours the achievement of “problem solving”. The second hypothesis was focused on testing if students with higher rates in problem solving competence obtain better results in their academic performance. The results indicated that active learning methodologies do not produce any significant change in the generic competence “problem solving” during the period analysed. Concerning this, we consider that students should work with these methodologies for a longer period, besides having a specific training. Nevertheless, a close correlation between problem solving self appraisal and academic performance has been detected.

Introduction

The Bologna Process (2009a) establishes the priorities for the European Higher Education Area (EHEA) until 2020. On the one hand, the significance of student-centred learning and the teaching function for the EHEA are emphasized. “Student-centred learning requires empowering individual learners, new approaches to teaching and learning, an effective support and guidance structures, and a curriculum which is more clearly focused on learners along the three cycles” (Bologna Process, 2009b). Active learning methodologies such as Cooperative Learning (CL) and Project Based Learning (PBL) can be found among the approaches adopted in teaching and learning. Besides, both of them have been recognized as appropriate methodologies in several documents related to the university context of engineering in Spain, such as “Libro Blanco del Título de Grado en Ingeniería Informática” (ANECA, 2004) and “Modelo Educativo UPM” (UPM, 2010).

On the other hand, one of the objectives of the EHEA is helping students to develop generic competences which they will use during their professional practice. Some of them are specific to one degree, but others are considered generic competences and can be achieved in most of the profiles: “planning and time management”, “teamwork” or “problem solving” among them. Whilst specific competences can be developed by carrying out
different teaching/learning tasks, some of the generic competences need specific training programmes to cover skill gaps during the degree.

The Educative Innovation Group DMAE-DIA (http://c3po.eui.upm.es/dmae/dmaeing.html) of the Technical University of Madrid has been using these methodologies for several years (García, Manzano, Pérez-Martínez and Muñoz, 2007; García, Pérez, Muñoz and Manzano, 2008; García, 2009; García and Pérez-Martínez, 2009; Pérez-Martínez, García and Muñoz, 2008; Pérez-Martínez, García, Muñoz, Sierra-Alonso and López, 2010). This group is aimed at: 1) achieving a more active participation of students in the learning/teaching process; 2) improving students’ academic performance by promoting specific competences and 3) promoting the development of generic competences. In the University School of Computer Science, this group is conducting some experiments in order to verify the influence of using different teaching methodologies both from the point of view of academic performance and the acquisition of generic competences. Some of these previous works (García, Manzano, Pérez-Martínez, Rodríguez and Alcover, 2010; Pérez-Martínez, García, Muñoz and Sierra-Alonso, 2010) do not show significant improvements in “Planning and time management” or “Teamwork” with the methodologies adopted during the academic years 2006/2007, 2007/2008 and 2008/2009.

In this work, we present the experience of applying CL, based on a jigsaw technique (Johnson, Johnson and Stanne, 2000; Felder and Brent, 2001), and PBL to an Operating System course. With PBL methodology, students face more open problems which need to be studied in a more autonomous way. The work developed by students with CL is more directed and they have to deal with well-defined problems. The study is aimed at evaluating the effect of these active learning methodologies on the development of problem solving generic competence.

Nowadays each university in the EHEA is defining the level of competences which their graduates must achieve. Every university needs to know the degree in which their graduates have reached that level. Traditional exams and written tests are focused on measuring the level acquired in specific competences, those related to subject contents. But there is less experience in measuring generic competences such as “problem solving”. Therefore, we consider it necessary to specify a mechanism to evaluate the influence that active learning methodologies have on the achievement of generic competences. The importance of this study is based on the use of verified and scientifically validated instruments to evaluate the effect of CL and PBL on the development of the skill “problem solving”. As far as we are concerned, no studies of this nature have been published before.

The following hypotheses were contrasted. Hypothesis 1: “The improvement achieved by students in the problem solving generic competence would be higher if PBL is applied to the subject (illstructured problems and autonomous work) than in those cases in which CL is applied (more directed work)”. Hypothesis 2: “Students with higher rates in problem solving competence obtain better results in their academic performance”.

This paper is structured as follows: Section 2 describes the experiment that developed. This way, we will describe the participants who have taken part in the study, the teaching
practice used, as well as the way in which data analysis have been carried out. Section 3 presents the study results. Then, discussion section will provide the conclusions of this work, some future proposals and the main limitations of this project.

**Method**

**Participants**

This study has been carried out at the Technical University of Madrid, where CL and PBL have been applied to two groups of Operating Systems subject: Operating System I (OS-PBL), taught in the fourth semester of Technical Engineering in Computer Science degree (second term of 2010), and Operating System (OS-CL), taught in the fifth semester of Computer Engineering (first term of 2011). Both subjects have the same syllabus, are taught in similar semesters, share formative objectives and use common teaching material. The latter syllabus, OS-CL, has been taught applying CL to a group of 19 students, who worked in groups of four students. The former, OS-PBL, has been taught applying PBL to 40 students, who were divided in teams of four components as well.

**Procedure**

Both subjects, OS-CL and OS-PBL, need to cover five topics: Introduction, Process and Threads, Memory Management, Input/Output and File Systems and have been taught for 15 weeks, with four hour per week, one two-hour theoretical session and another two-hour laboratory session.

In the subject OS-PBL, the tasks which constitute the project will be carried out by groups of 4 or 5 students, on the one hand. This project is aimed at making a comparison between the operating systems Windows XP and Linux along the course, regarding the aspects included in the syllabus of the subject. At the end of the term, students should be able to explain a series of essential differences and similarities between both operating systems, from the point of view of their interface, implementation and performance. The project will be divided into 4 tasks. Students will tackle a different topic in each of the works, which will be related to the contents of the syllabus. The professor will suggest a series of topics; however, any group can work on another topic suggested by them, which has to be previously agreed with the professor. The development of each topic consists of three phases. First, students carry out a search and study of information. Then, they have to design an experiment approaching the comparison between Linux and Windows XP, with regard to the topic studied. Finally, they present a report with all the work carried out, including the results obtained in the experiment, and also make an oral presentation. At the end of the term, a debate is established focusing on all the projects developed by students in order to answer a series of open questions: Are Linux and Windows XP actually so different? Is there any significant difference regarding their performance? Does any of the operating systems offer more advantages from the point of view of programming?

On the other hand, CL was applied to the fifteen OS-CL sessions. At the beginning of the course, permanent groups of four students (base groups) were formed. Because of CL,
each member of a group had to be an expert on some basic concepts of the topic during each session. For this reason, the kind of homework which students were given depended on the type of expert. There were four kinds of homework, one addressed to each expert. For each session, this homework was structured into three parts: the first described the learning objectives and skills to be acquired with the homework; the second indicated the information to be studied, and the third part consisted in solving basic problems, developing a simple programme or answering some questions. Both the second and the third part were set estimated periods of time to be carried out. Homework had to be handed to the professor before the session concerned started and the real amount of time it took them to do it had to be indicated. Along each session, CL method was put into practice and all base groups tried to solve a problem which required the knowledge of the four experts (jigsaw). At the end of the session there was a global discussion about the difficulties encountered and the different ways to solve the problems.

Several individual written assessments were made along the term. More specifically, three test, three short-answer questionnaires and two problems. These assessments were very similar in both courses. The individual mark obtained in these tests meant 50% of the final mark.

**Measuring and Instruments**

The instrument used to measure the problem solving competence is the Problem Solving Inventory test (PSI) (Heppner, 1988) whose purpose is to assess a students’ perception of his or her own problemsolving behaviours and attitudes. It has 35 items and is divided into three scales: Problem-Solving Confidence (CON), Approach-Avoidance Style (AA) and Personal Control (PC). The results obtained according to three scales can be analysed individually, although a total PSI score can be used as a single index of problem-solving appraisal.

In each item (statement), participants have to evaluate their own perception following a 6-point Likert type scale (1 = Strongly Agree; 6 = Strongly Disagree). Therefore, low scores on all scales and for the Total PSI score represent positives appraisals of problem-solving abilities. This test was filled out by students of both courses at the beginning and also at the end of each term.

**Data analysis**

For the Statistical Analysis we used version 5.1 of the statistical program STATGRAPHICS (SPSSInc., 2006). In order to test the first hypothesis, the effect of CL and PBL on problem solving competence, we compared the mean obtained in the PSI test measured both before and after active learning methods. This work was made individually in OS-CL and OS-PBL. The Kolmogorov-Smirnov test was used to determine if data can be adequately modelled by a normal distribution. We run a t-test with a significance level of 0.05 to decide whether the equality of the means could be considered.

The second hypothesis was tested by analysing the correlation between PSI scores and the marks obtained by students in the individual assessments. The Pearson Correlation
Coefficient was used with a significance level of 0.05. More specifically, we analysed the correlation between PSI marks and four written individual marks: MT (mean mark obtained in tests), MQ (mean mark obtained in shortanswer questionnaires), MP (mean mark obtained in problems) and MI (individual global mean mark).

### Results

Table 1 shows the means and standard deviation obtained for each subscale and the total PSI test. All these variables fit a normal distribution, according to Kolmogorov-Smirnov test. In order to test hypothesis 1, a t-Student test for related measurements (with a significance level of 0.05) was used to compare the means obtained in each variable at the beginning and at the end of the course as well.

A statistically significant difference was not found when comparing PSI means, neither in the OS-CL group nor in the OS-PBL group. In the OS-CL case, we obtained $t_{[15]} = 1.226$, $p=0.243$, whilst in OS-PBL group the results were $t_{[33]} = -0.156$, $p=0.877$. As far as subscales is concerned, the only case in which we obtained significant differences was the AA scale in OS-CL ($t_{[15]} = 2.539$, $p=0.023$). The other subscales of the OS-CL group as well as every subscale of OS-PBL showed high p values.

<table>
<thead>
<tr>
<th>Generic Competence</th>
<th>OS-CL</th>
<th>OS-PBL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>beginning</td>
<td>end</td>
</tr>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Approach-Avoidance Style (AA)</td>
<td>48.63 (8.831)</td>
<td>45.19 (8.248)</td>
</tr>
<tr>
<td>Problem-Solving Confidence (CON)</td>
<td>27.19 (7.432)</td>
<td>28.56 (6.572)</td>
</tr>
<tr>
<td>Personal Control (PC)</td>
<td>15.94 (3.021)</td>
<td>15.81 (3.311)</td>
</tr>
<tr>
<td>Total PSI score (PSI)</td>
<td>91.63 (16.633)</td>
<td>89.56 (15.077)</td>
</tr>
</tbody>
</table>

Regarding hypothesis 2, Table 2 shows the Pearson Coefficient and the significance level for each variable correlation. Significant correlations are marked with asterisks: (*) if the significance level is 0.05 and (**) if the significance level is 0.01. As it has been explained before, low scores on all scales and for the Total PSI score represent positives appraisals of problem-solving abilities. Therefore, we should highlight negative correlations, which point out that the more positive appraisal the student has about his problem solving ability, the better mark he obtains in the individual assessment.
Table 2. Pearson Correlation Coefficient between PSI and individual marks

<table>
<thead>
<tr>
<th></th>
<th>OS-CL</th>
<th>OS-PBL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MI</td>
<td>MT</td>
</tr>
<tr>
<td>Approach-Avoidance</td>
<td>-590</td>
<td>.057</td>
</tr>
<tr>
<td>Style (AA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem-Solving</td>
<td>-479</td>
<td>.300</td>
</tr>
<tr>
<td>Confidence (CON)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal Control (PC)</td>
<td>-601</td>
<td>.007</td>
</tr>
<tr>
<td>Total PSI score (PSI)</td>
<td>-553</td>
<td>.013</td>
</tr>
</tbody>
</table>

Although the strongest correlations have been obtained between PC variable and OS-CL individual marks, the only scale that shows correlation with individual marks on both courses is Problem-Solving Confidence (CON). It particularly has a correlation with the overall mean mark (MI) with a significance level 0.05. If we compare both courses, we observe that a stronger correlation is found in OS-CL.

Discussion

Regarding the first hypothesis, we can conclude that the application of CL and PBL methodologies did not suppose a significant improvement to students in the “problem solving” competence when it is measured at the beginning and at the end of the term. These measures contradict the conclusions described in some previous studies (Dochy, Segers, Van den Bossche and Gijbels 2003), that suggest a positive effect of some active learning methodologies on both, applying knowledge and improving skills.

Several studies have checked the validity of the PSI test (Heppner 1988; Sahin 1993) and we have found two reasons that could explain the results obtained in this work. Firstly, a semester may be a very short period of time to obtain significant improvement in the measures carried out at the beginning and at the end of the term in which the methodologies have been used. Secondly, it is possible that the methodologies alone do not improve the generic competence that we studied. We conclude that students need some specific and extensive training on “problem solving” before applying it to learning methodology. In the next years, we will include some seminars to guide students in the development of generic competences. Besides, we will programme the competence measures in order to assess students’ progress along several years. Finally, we highlight the advisability of having a control group with traditional lectures so that we could study the significant differences with active learning methodologies.

As far as the second hypothesis is concerned, we observe certain correlations between problem solving self-appraisal and individual marks. In particular, the scale Problem-Solving Confidence (CON) seems to be the most constant since the correlations happened in both courses. Besides, the lowest correlation obtained with the Approach-Avoidance (AA) variable could be explained by the kind of problem solved individually by students in
the written tests. These problems are well-defined and short, so they do not require and important strategy to be solved.

In future years we find greatly important the integration of a general competences training in current curricula. The proposal will consist in developing a map which distributes general competences among semesters in a balanced way. The subjects which constitute a semester will imply some practical credits so that the general competences selected for this semester could be taught. Then, subjects will foster the use of these skills and they will require that students show enough ability related to these skills according to the training they have received. The first terms will deal with basic competences, ‘teamwork’, ‘problem solving’, ‘written expression’ and ‘time management’ among them. Further terms will tackle more advanced competences.

**Limitation of the Work**

The limited number of participants may have influenced the results. In further years, a higher number of students will follow this subject. This way, a deeper analysis will be possible.

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Reports from teaching practice: experiences and management of tensions encountered with PBL implementations in the early years of undergraduate engineering education

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Abstract: In engineering education, problem-based learning (PBL) environments are utilized in senior years (through design capstone courses) and increasingly in the first and second year undergraduate education. Faculty who implement PBL in the first two years face unique challenges and tensions with regard to PBL and elements of engineering education reform. This research study investigated how US faculty (n=313 for survey and n=14 in-depth interviews) experienced and managed the tensions. Findings show that faculty particularly managed the tensions by (1) setting and explaining expectations to help students understand the new learning environment, and (2) by tailoring the learning activities to the level of the student. Details and further research directions are described in the paper.

Keywords: innovative pedagogy, PBL, tensions, engineering education

Introduction

The demands on engineering educators are high and they are being challenged to create learning environments that not only teach technical skills better, but also incorporate professional skills commencing in the first year of engineering programs (Sheppard, Macatangay, Colby, & Sullivan, 2009). While technical knowledge and skills made up the bulk of engineering curricula (Trevelyan, 2008), these were not the only skills required of engineering graduates. Industry has been demanding a new type of engineer with skills that include both technical mastery (Duderstadt, 2008) and professional skills such as self-directedness, teamwork, and communication.

The challenges facing engineering schools are to better prepare engineering graduates for professional practice, and to help them transfer knowledge and skill to practice (Aparicio & Ruiz-Teran, 2007; Said, Adikan, Mekhilef, & Rahim, 2005; Savin-Baden, 2008; Stinson & Milter, 1996). Of particular note is that the traditional approaches to education (teacher-centered, lecture-based) have done little to prepare students to address complex real world problems (Brodie, Zhou, & Gibbons, 2008). Education has seen a progressive shift, at least in theory and intent, to a more learner-centered focus (Bransford, Brown, & Cocking, 2000) and away from the traditional teacher-centered instructional approach.
Learner-centered pedagogies that support active and collaborative engagement of students promote deep learning and sustained knowledge and skills development (Biggs & Tang, 2007; Ramsden, 2002).

Problem-based learning, a learner-centered pedagogy, has been conceptually brought into the realm of engineering education under various names - problem-based learning (PBL) (Brodie et al., 2008; Butun, Erkin, & Altintas, 2008), project-based learning (PjBL) (Edward, 2004; Lima, Carvalho, Flores, & van Hattum-Janssen, 2007), and problem-oriented project-based learning (POPBL) (Lehmann, Christensen, Du, & Thrane, 2008). The call for increased design-based curriculum in engineering education (Sheppard et al., 2009) is also reflected in newer curricular strategies such as Conceive-Design-Implement-Evaluate (CDIO) (Crawley, Malmqvist, Östlund, & Brodeur, 2007). The effectiveness of problem-based pedagogies has been demonstrated for long-term knowledge retention, skill development, student and faculty satisfaction (Strobel & van Barneveld, 2009), as well as increased motivation and engagement of students, increased self-directed learning skills, and an increased integration of theory and practice (Ribeiro, 2008). PBL is predominantly seen in the later years of the engineering program (i.e., capstone courses) where the primary drivers for PBL implementation included the opportunity for students to transfer skills, and to practice and apply professional skills and attitudes (Mitchell & Smith, 2008). The primary drivers for PBL implementations in the first and second years of their undergraduate programs included a need to integrate professional skills, to demonstrate relevance of the foundational knowledge and basic science to the practice of engineering, to engage and retain students, and to support deep learning and transfer of knowledge and skills (Froyd et al., 2006; Molyneaux et al., 2007).

In the pursuit of reform, the role of engineering faculty as the implementers of pedagogical change becomes critical (Barr & Tagg, 1995). They are, to a large extent, the instigators of reform within their classrooms and the implementers of innovative pedagogical approaches. Most engineering educators implemented PBL of their own accord and in an incremental fashion (Inderbitzin & Storrs, 2008). The adoption of PBL into their teaching practice is important to its establishment in engineering education and necessitates a new way of conceptualizing teaching and learning. Schneckenberg (2009) argued, though, that faculty faced tensions within the various levels of the embedded systems and contexts in which they found themselves as they considered the adoption of innovations. From an activity theory perspective, the introduction of a new pedagogical implementation in the classroom system (an innovation) brings with it a set of tensions (Engeström, 2001). Tensions may arise within each level of the system, as each may have its own goals, rules, values, processes and procedures that facilitate or constrain the interactions within and between systems. The teaching beliefs and intentions of educators may be impacted by the facilitate/constrain parameters of a system.

The introduction of an innovative pedagogy such as PBL brings with it a set of tensions (Hung, Bailey, & Jonassen, 2003) and compounds the tensions already identified in engineering education reform efforts (Crawley et al., 2007). To what extent engineering educators encountered these tensions with the implementation of PBL in their teaching practice and how they managed the tensions remains unexplored.
Research questions

The purpose of this study was to identify the extent to which engineering educators’ encountered tensions with the implementations of PBL in their teaching practice, both at the classroom and at the system level. In the specific context of the first two years of undergraduate engineering education, the research questions are:

1. Based on their teaching practice, what are the predominant tensions encountered by engineering educators?
2. How do engineering educators manage these tensions?

Theoretical framework

In the context of this study, the definition of PBL is informed by the definitions offered by Barrows (2002) and Savery (2006), but remains intentionally broad and inclusive of other problem-focused pedagogies. While we adhere to the concepts that the problem is central to the learning and should be ill-structured (open-ended), we are neutral in our stance on whether PBL implementations should be at the course or curriculum level. Barrows’ (1986) taxonomy of PBL methods acknowledged the different ways that PBL could be implemented based on the variation in context and objectives of the particular learning environment. Therefore, in the rest of this document, PBL is described as a supported learner-centered environment that makes use of open-ended problems as the basis for learning both technical and professional knowledge, skills, and attitudes. Additionally, we use activity theory (Engeström, 2001) as a lens through which to understand that implementations of innovations such as PBL are, in fact, a human activity system (e.g., classroom level) embedded within a larger system (e.g., institution level) that represents a culture, a way of being, and a set of objectives and goals. Within these interacting systems exist tensions that could be envisioned not as problems, but as opportunities for change and transformation.

Methodology

In this study, we defined our population as engineering educators in the Unites States. We took a twophased approach to data collection: (1) a survey and (2) semi-structured interviews. An online survey was launched to capture data about the experiences of engineering educators with PBL implementations and the tensions encountered (Phase 1). Hung et al. (2003) identified five tensions associated with PBL implementations and Crawley et al. (2007) identified five tensions associated with engineering education reform. Survey respondents were provided with each set of tensions taken from the research literature and asked to force-rank them in order of frequency with which they were encountered. It should be noted that the forced-choice aspect of these questions provided data about the relative frequency of the named tensions in relation to each other, and does not imply that top ranked tensions occur all the time in one’s teaching practice. Survey data was analysed to produce descriptive statistics of the sample of respondents.
The survey subsequently served as a sampling strategy and respondents who were utilizing PBL in the first and/or second year of their engineering programs were invited to participate in semi-structured interviews where they could further describe their experiences and management of tensions that were of most concern to them (n=14) (Phase 2). Digitally recorded interviews were transcribed and thematically analysed (Braun & Clarke, 2006) in order to identify themes of how these 14 engineering educators managed the tensions that they encountered with PBL implementations in their teaching practice.

**Findings**

The final survey sample consisted of 313 engineering educators (71% male, 27% female, 3% no response) from degree-granting universities in the United States. The prevalent engineering domains represented by the sample were Mechanical (37%), Electrical and Computer (21%), Chemical (18%), and Civil (18%).

The majority of respondents were:

- from large research universities (62%),
- had between 6 and 15 years of engineering teaching experience, and
- held positions of full or associate professor.

The subsequent sampling approach secured 14 participants to engage in semi-structured interviews to further explore their strategies to manage the tensions encountered.

**Predominant PBL tensions encountered in engineering teaching practice**

Participants reported that the most frequently encountered PBL tensions, of the ones given, were the discomfort that students' experienced in their initial transition to PBL versus their subsequent positive attitudes once the transition was made, and the issue of content coverage as indicated through the tension between depth and breadth of curriculum (Table 1). Hung, Bailey, and Jonassen (2003) defined the tension of student discomfort as “students find the initial transitions into PBL to be difficult. Ultimately, though, they become generally satisfied with PBL...once the transition is made” (p. 17) and the tension of depth versus breadth of curriculum as “the PBL method limits the possibility of students being exposed to broader content that may be a part of a course or program of studies but may not be directly related to the causes or solutions of the problem under investigation” (p. 13).
Participants reported that the most frequently encountered engineering education reform tension, of the ones given, was problem-solving versus design (Table 2). This tension might be best understood by looking at different conceptualizations of what a problem is. While, Holt, Radcliffe, and Schoorl (1985) argued that problem solving implies a focus on a ‘fix it’ mentality of tidy problems with a readily found solution as opposed to engineering design that required innovative and creative views, many other disciplines consider problem solving as something ill-defined and wicked (Jonassen, 1997). The other four of the five engineering education reform tensions appeared to be clustered closely together (Table 2). The second most frequently reported tension, theory versus application/practice, was described by Mills and Treagust (2003) as a tension between teaching fundamental engineering science and content knowledge versus teaching how to apply the learned knowledge in practice.

Management of tensions

Fourteen engineering educators agreed to participate in interviews to discuss their management approach to tensions of most concern to them. The tensions that received the
most attention, student discomfort, depth versus breadth, and role as teacher versus facilitator, were all within the PBL set of tensions as opposed to the engineering education reform area. This is not completely surprising, as the engineering education reform tension tend to be situated with the larger system, whereas the PBL tensions are situated within the educator’s classroom where he/she may have more control and influence over the management of the tensions.

Analysis of the transcripts revealed two main themes related to the management of students’ discomfort with the initial transition to a PBL environment. The transition of students to PBL was supported by (1) setting and explaining expectations to help students understand the new learning environment, and (2) by tailoring the learning activities to the level of the student.

With regard to the management of the tension of depth versus breadth of the curriculum, three themes emerged. Educators made adjustments to (1) the learning environment by initially providing more structure and constraints for assigned problems/projects, modifying the scope of the problem to make is doable and relevant to the student, (2) the use of class time by using a hybrid/blended approach to minimize lecture and focus class time on exploration and hands-on activities, and (3) the content by reducing the breadth and focusing on need-to-know content and removing content that was duplicated in other courses.

Finally, two themes were defined for the management of the tension between the traditional role as teacher versus the role as facilitator in PBL. Educators managed this tension by (1) shifting the relationship between the content, the student, and the instructor in order to put more of the onus for learning on the student, reframing their engineering educator identity and (2) optimizing the educator’s role and use of time by offloading basic administrative functions and using class time for key points, discussion, activities, and practice, and have students work in groups to take advantage of team/peer learning.

In conclusion, engineering education reform continues to move toward outcomes-based programs, PBL has been noted to be a pedagogy poised to meet the learning needs of engineering students. While the engineering educators encountered tensions at both the classroom and the system level, those who incorporated PBL into the early years of their engineering programs tended to focus their energies on managing tensions at the classroom level. This approach appears logical, in that this is the level at which educators had not only greater controller of the environment, but also had the potential to have a greater impact on their students’ learning and development as engineers of the future.

**Future research plans**

Our preliminary findings may be relevant for (1) professional development programs, carrying appropriate incentives, for educators who want to implement PBL into their teaching practice, (2) administrators/policy makers who are planning curriculum redesign to meet outcomes-based program accreditation needs and ways to support their faculty.

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Future research may include three directions: (1) gaining complimentary insights from perspectives of students in PBL environments, particularly those transitioning from high school and non-PBL environments, (2) implementing strategies to increase the ability to manage tensions encountered, and provide support structures for PBL implementation and researching their effectiveness, and (3) researching implementation differences in order to further contextualize the tensions and learn from the teaching practice.

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Abstract: In this paper we report the process of designing and building the EYEFLY 1, a real UAS platform which has just performed its maiden flight. For the development of this aircraft, 30 groups of students from successive years at the Escuela Universitaria de Ingeniería Técnica Aeronáutica (EUITA) of the Universidad Politécnica de Madrid (UPM) carried out their compulsory End of Degree Project as a coordinated Project Based learning activity. Our conclusions clearly indicate that Project Based Learning activities can provide a valid complement to more conventional, theoretically-based, teaching methods. The combination of both approaches will allow us to maintain traditional but well-tested methods for providing our students with a sound knowledge of fundamental engineering disciplines and, at the same time, to introduce our students to exciting and relevant engineering situations and sceneries where social and business skills, such as communication skills, team-working or decision-taking, can be put into practice.

Introduction

The context

The principle which would eventually lead to the new paradigm in engineering education crystallized in a series of documents published in America in the years around the turn of the century. In 1966 the Boeing Company published the list of desired attributes of an engineer (Boeing 1996). The new accreditation standards (ABET EC 2000) reflected the
ideas over engineering education which had been put forward in the previous decades. In 2001 MIT launched the CDIO Syllabus (Crawley 2001).

Paralleling this process, in Europe, a complete re-structuring of the higher education system was taking place. The starting point was the declaration of the ministers of higher education of European countries commemorating the anniversary of the oldest university in the world: Bologna.

Both processes present such a wide and fertile variety of education theories and methodological tools that resuming them in a simple sentence would undoubtedly be a futile intent. However it will be generally accepted that the distinct feature they both share is the adoption of a Learner’s Centred Approach to teaching.

It is against this methodological background that the conception and development of the Project Based Learning (PBL) activity which we present in this paper has taken place.

For over 75 years the formation of aeronautical engineers in Spain was exclusively the responsibility of two schools: the Escuela Técnica Superior de Ingenieros Aeronáuticos and the Escuela Universitaria de Ingeniería Técnica Aeronáutica (EUITA). The former offered a five-year degree program whilst the latter offered a 3 year-degree program. As a consequence of the so called Bologna Process, a political decision was taken that all graduate degrees in Spain must be 4-year-programs. Thus, both Schools merged to create the Escuela de Ingeniería Aeronáutica y del Espacio (EIAE), which is already offering the new four-year-bachelor degree in aerospace engineering.

Simultaneously to the design process of the new curriculum, a group of professors from the EUITA Aeronáutica had undertaken the development of an engineering project: the design and building of Unmanned Aerial System (UAS). They soon realized that this engineering project could be approached as a Project Based Learning activity to be developed by the students as part of their compulsory Final Project.

By taking this initiative we expected to acquire enough knowledge and expertise to decide whether a multidisciplinary-teamwork PBL activity could be introduced as part of a conventional lecture/laboratory based curriculum. If this was the case, we also intended to know whether the adoption of this Project Based Learning approach would be useful to actuate on those learning areas which would have to be enhanced in the new curriculum, namely personal and professional skills, teamwork, communications and those activities enabling the integration of conceptual knowledge and technical skills to the designing and building of engineering products.

Thus the objective of the PBL activity described in this paper was twofold: designing and building a real and industry competing UAS and testing the adoption of a PBL as an influential part of our new curriculum without changing it to a pure PBL

**Theoretical framework**

Project Based Learning is considered as one of the best examples of the socio-constructivism. As opposed to skinner’s behaviourism, constructivism, and more
particularly socio-constructivism, understands learning as a process where the
construction of knowledge derives from building on previous knowledge and interacting
with the environment, that is, what we understand is a function of the content, the context,
the activity of the learner and of the learners’ own goals (Savery & Thomas 1995).

However there is not a single specific theory from which it can be said that PBL is directly
derived, rather, there are various constructivist schools of thought (Thomas 2000) whose
ideas have foster PBL, both as a teaching and learning method and as a curriculum
development.

Furthermore, new insights on PBL history (Kolmos 2004, 79) seem to conclude that the
link between PBL and any particular theoretical corpus has only very recently been
established and that the source originating PBL as a teaching and learning approach was
rather a number of pure pragmatic experiences, using the trial and error method to
develop it. This might well be the case for a very adequate use of the saying “there’s
nothing so practical as a good theory and there’s nothing so theoretically interesting as
good practice” (Gaffney & Anderson in Savery & Thomas 1995).

The lack of a universally accepted opinion on its origins and the variety of features which
have been considered as typical of PBL had made it difficult to reach a common and
comprehensive definition of this concept. Probably one of the simpler and most significant
definitions is the one provided by J.W Thomas when he says that PBL is a model that
organizes learning around projects.

The model some Scandinavian engineering universities and schools have adopted is
precisely the organization of the whole curriculum around projects. This is consistent with
some definitions of PBL which use the term only for those situations where projects are
central to curriculum (Synteta 2003).

As we have previously indicated we had neither the capacity nor the intention of
reorganizing a curriculum which had just been developed on the basis of a well-
established and long tested previous model. Our aim was not to make the PBL activity
proposed a central part of the curriculum, but nor did we plan it to serve as a pure
complementary practice, which was the role of the existing Final Project. We would like it
to be influential enough as to develop some students’ skills and aptitudes which were not
completely emphasized in the curriculum.

To resume, if our research had to be listed under one of the four different forms that,
according to John W Thomas (Thomas 2000), research on PBL takes, this would be the
first one, that is the one whose purpose is to make judgments about the effectiveness of
PBL; although we do not consider its effectiveness in a broader sense but only with
respect to the goals we have exposed above.

Methodology

We consider that the principles of the CDIO didactic approach are a good materialization
of the new paradigm in engineering education. Conceive, design, implement and operate
are the stages of a product development and engineering studies should also be planned adopting that point of actuation. Thus the project – on the small scale- has swept through all the different stages of an aerospace project.

**Definition of requirements**

The aim of the project was to design an UAV for civil aerial observation. Once its mission had been defined, a wide research analysis of similar airplanes was carried out since, in the initial stage of the project, it is quite common to look at similar airplanes for estimating some important data of our design. Next, the preliminary sizing was undertaken, taking as a basis weight and wing loading estimations, the latter parameter being essential because it will allow us to study one of the most important elements of the plane: the wing.

The objective of the first working team was to establish an initial airplane layout, taking into account that many modifications will be required as the development of the project progressed.

Previous to the preliminary sizing, another group of students devoted themselves to study similar airplanes. In this way we were able to compare common features shared by different aircraft and to estimate, at this first stage, some numerical values which were needed for the pre-design stage.

**Analysis of Similar airplanes (State of the art)**

By means of carrying out a comparison with similar planes, on a first approach, parameters were estimated: maximum takeoff weight, payload, range, altitude, and cruising speed.

- Maximum weight at take-off: 30 kg.
- Payload: consisting of a video camera (or webcam), batteries and an air-to-ground radio transmitter.
- Range: an estimated value of 425 to 450 km with maximum payload and a 10% fuel reserve. Altitude: approximately 800 m.
- Cruising speed: around 30 to 34 m/s

**Preliminary sizing**

In the pre-design stage we specified two main parameters: weight estimation and wing loading estimation.

**Weight estimation**

We concluded that the preliminary values for weights would be:

- Maximum take-off weight: 30 kg.
- Empty weight: 13 kg.
- Fuel weight: 8 kg.
- Maximum payload: 8 kg.
These values are selected taking into account the endurance and range requirements, and the payload required for civil aerial observations (digital infrared camera, etc.)

**Wing Area Estimation**

Before calculating the wing area, and, therefore, being able to establish our prototype’s wingspan, we needed to calculate the wing loading. This value was conditioned to the corresponding phase of flight we are going through; as a consequence, we had to determine the wing loading for each of the possible situations. Wing loading depends on the following conditions: stall speed, take-off run length, landing distance, cruising speed, climbing speed, time of climb to a specific altitude, maneuvers.

**Initial Layout**

Once all the preliminary sizing data had been determined, the following stage of the project was deciding the aircraft’s layout.

Making a decision on the type of fuselage to be used was one of the first objectives of this stage. The main requirements that the fuselage structure should meet were the following:

- An aerodynamic design.
- Light weight (an essential element for our design).
- Not difficult to manufacture and assemble.
- Easy to maintained.
- Maximum cargo capacity (open plan structure).

Figure 1. Shows the draft of the initial plan view and the profile of the initial configuration of our design

**Aerodynamic Analysis**

The following stage in the project, after determining the preliminary configuration, was calculating all aerodynamic features and the aircraft’s performance so that they could later be checked and recalculated. To complete all these steps, a sound analysis of the most
important elements of the aircraft had to be done, from the geometric and the aerodynamic points of view.

**Analysis of the aircraft's flight dynamics**

We approached the analysis of the aircraft's performance from three different points of view:

- First, a study of the performance by means of calculating the different power values, that is to say the power required for flying and the power developed by the power plant.
- Next, we calculated the basic performance characteristics from three different approaches:
  - Maximum and minimum speeds of flight, as well as rate of climb (maximum and optimum).
  - Theoretical and practical ceiling as well as calculation of the time of climb.
  - Flight envelope calculation.
  - Flight range and endurance.
- Finally, we undertook the analysis of special performance, establishing take-off and landing run distances as well as maneuvers.

Previous to all this, was determining the power available which was defined as the product of the propeller efficiency by the power developed by the engine. Therefore we needed to know the propulsive efficiency, for the different flight conditions, by defining the characteristic parameters of our propeller.

- Selecting the type of propeller or the family of propellers.
- Matching the propeller to maximum efficiency condition.

Once the required power and the power available had been defined, we could embark on the analysis of the basic performance.

After the study of the performance, we proceeded to check dynamic and static stability, together with the aircraft control characteristics.

**Analysis of the aircraft’s structure**

Once the study of the airplane from the aerodynamic point of view was completed, we had to carry out a basic structural study.

Before doing so, we needed to determine the maneuvering diagrams.

**Wing tunnel tests and drag checking**

Before constructing the final prototype and as an essential part of the whole project, we carried out a series of test at our workshop. We concentrated on testing aerodynamic forces using our wind tunnel. We also checked the most critical structural elements by means of static load tests.
Building the prototype

After we had concluded the stage corresponding to the preliminary essential calculations we moved forward to the detailed design and manufacturing stages. A global design was developed and we had to define materials, joining elements and fasteners. The assembly of the prototype and the actuations to get it ready for flight was the last stages of the project.

To sum up this part we would like to point out that we had not set out to establish a new mark nor conquer a pre-established level. We considered that the challenge of placing the responsibility for the whole project in the hands of the students would be valuable in its own right, because it would imply nothing less than their being responsible for all the stages mentioned.

Nine years have gone by since the starting point and we are now in a position to state that it has been a truly rewarding experience and that we can now see the flight of the UAV on the horizon. The following are just a few figures of what this effort has required:

- More than 15000 hours/man.
- 46 students (their enthusiasm and dedication).
- About 20000 €.
- Great amounts of patience.

Conclusions

Our main conclusions are related to the research questions we started from:

1. Is it possible to produce in an academic setting a real UAS technically comparable to any other produced by conventional aircraft manufacturers?
   a. The answer to this first question is evident: the Eyefly 1 (Fig 1) has already made its maiden flight.
2. Could this task, taken as a multidisciplinary-teamwork PBL activity be introduced as part of a conventional lecture/laboratory based curriculum?
   a. The fact that the aircraft has been designed and built in the academic setting and as part of the curriculum clearly allows us to give an affirmative answer to this question, too.
   Once again we must repeat that we did not set off to build a new curriculum round project based learning activities. Our aim was to design an activity which could balance the possible weaker points of a well tested high performance curriculum. Our project did not intend to be the central activity of the curriculum. However we have found that the project has influenced the methods and learning techniques of some specific subjects, providing a real reference for some rather theoretical points.
   The beneficial effects are very evident, such that a new project has already started: a VTOL aircraft is being designed. This time we will try to introduce the development of some of the initial stages at some point around the middle of the curriculum, so that students at the end of the second year can participate. In this way we would try to follow the suggestions of the CDIO Initiative which recommends “...a curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level” (CDIO Standards 2004).

3. We also wanted to know whether this kind of PBL activity would be useful to enhance personal and professional skills such as teamwork, communications and those activities enabling the integration of conceptual knowledge and technical skills to the designing and building of engineering products.
   a. With respect to this question our position was not completely neutral. All the studies on the effectiveness of PBL from Barrows to the present moment (Kolmos 2004) indicate that the skills referred to are precisely the ones more positively developed by a PBL activity.
   Although no quantitative assessment has been carried out yet, we are certain that in our case the capacity to communicate with others, working in teams and integrating conceptual knowledge into real products have largely and positively increase by the students involved in the design and building of the EYEFLY 1. As opposed to this, some of the greatest difficulties which both students and teachers have had to face have been in the area of team coordination, ability for building and assembling, lack of solid financial support and the constant doubt of reaching success.

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Abstract: The year 2010 was considered the deadline of the Bologna Process in higher education in Spain; however it can still be considered a work in progress. Although it could be argued that syllabus reform is practically completed, methodological renewal is the battle that is being fought on the day-to-day implementing of new degrees. In this paper, the work undertaken across an undergraduate course in generating a local capacity for innovation and fortifying the implementation of a new degree supported by methodological renewal is discussed. The use of an Educational Innovation Group (Grupos de Innovación Educativa, UPM) as a tool to generate new practices and support services, to make resources available for innovation and to influence the learning environment at the educational centre is exemplified. In our scenario, a current situation in which the feeling of nothing-is-going-to-change has already become ingrained, innovation should be considered more a change planned as a response to the problems we perceive at our educational centres and on our degree courses, rather than thinking of it as the introduction of a new method or methodology. In this sense, the view of a degree course as a unit and common project is indispensable in channelling the initiatives required to improve education and learning. The generation of an environment and local capacity for innovation in the educational centres is the route to be taken in achieving real methodological renewal.

Introduction

The year 2010 was considered the deadline for the implementation of the Bologna Process in higher education in Spain. From September 2010 access of new students to the pre-Bologna degree courses was no longer permitted, by which all undergraduate and postgraduate courses were to be adapted to the European Higher Education Area (EHEA).

Has the reform achieved its objectives? The provision of a specific answer to this question, one which appears to be arising in many forums, would be somewhat premature. Unfortunately, the consequences of the important changes associated with the Bologna Process are not only uncertain but also slow. Added to this complexity is the fact that such changes, even in analogous learning environments, are neither homogeneous nor easily comparable.

In addition to this, it should be taken into account that the Bologna Process includes, together with reform of studies, significant educational and methodological renewal.
Although it could be argued that syllabus reform is practically complete, methodological renewal is the battle that is being fought today. This is the reality of the day-to-day teaching of new degrees, and one which will continue to remain over the coming years, at least until the transformation of all the courses has been completed. At present, the principal questions which we should ask are those that follow: Are we taking the right steps in completing the process of methodological reform? Is methodological change being left to die, with the Bologna Process being converted into syllabus reform? Has the EHEA process meant a change in the paradigm and has it moved, in real terms, from teaching prominence to student learning prominence?

Many Spanish universities have developed measures designed to encourage educational innovation processes among the lecturing staff. Different from curricular reform, in which educational centres and departments have been fully involved in forming new syllabuses, methodological renewal has always been viewed from the general perspective of the institution. In fact, those initiatives undertaken in educational innovation are generally managed and fostered from the respective office of the vicechancellor at each university. The application of this model encounters certain problems, such as those listed below:

- It has little effect on the learning environment at the educational centres, something which is the key to implementing significant change.
- It moves responsibility for innovation far away from the educational centres where teaching is taking place.
- It is seen by those responsible for application of new methodology as an obligation and a restriction of didactical freedom, imposed from outside.
- In many cases, it seems to generate solutions in search of problems, instead of focusing on solving the actual problems.

The consequence is that a significant part of the message that should be transmitted to the lecturing staff is lost along the way. Initiatives in educational innovation, given that they are generally undertaken by individual lecturers and affect only specific modules, are unable to respond to a wider strategy across the degree course. On occasions, they even clash head-on with the allocation of resources and the objectives of such courses.

The situation, examined from the viewpoint of the students, can generally be a little disconcerting; lecturers eager to incorporate new methods work, even within the same module, alongside lecturers who practise the old methodology with traditional education and assessment systems. All of this, without an extensive criteria and strategy, could lead to rejection by the students of the more innovative lecturing staff, given that it obliges them to enter areas which create some degree of agitation and uncertainty.

Within the process of large-scale change, a necessary intermediate state emerges. Such a scenario appears to be that of the current situation; after extensive change in study programmes we now find ourselves at the point of application. Monitoring the events occurring during such a state is indispensable and, at the same time, extremely difficult. A change that affects aspects of great depth, such as the ways of teaching and student learning, is one that generates strong opposition. Each time educational initiatives lose a
battle, the forces of resistance to change will become ever intense. In many educational centres the idea that nothing is going to change has already become ingrained.

What is required for change to commence, on many occasions, is very different from that needed to keep it alive. In order for them to adapt to the specific needs of every moment, the tactics should be flexible; and for this to happen it is necessary to act with speed. The view of the authors is that at a key moment such as this, the initiatives designed to enhance education and learning that are centred on a degree are those that have most influence and it is at this level at which the true ability to manoeuvre is found. Educational innovation should be considered as change planned to respond to the specific problems perceived at educational centres and on degree courses, better than to be considered as the introduction of a new method or technique. Hence, the objective of this article is to highlight the work undertaken across an undergraduate course, in this case the Degree in Materials Engineering, in generating a local capacity for innovation and fortifying the implementation of a new degree supported by methodological renewal.

The context

As many of the problems in education are specific to certain educational centres and degree courses, it is essential that the particular characteristics of each context be known. In the case of this study, the level one lectures given in the Degree in Materials Engineering commenced at the School of Civil Engineering in September 2009, with the course being one of the first at the Technical University of Madrid (Universidad Politécnica de Madrid, UPM) to be adapted to the Bologna Process. In addition, this was the first occasion that a degree in this discipline had been offered in Spain.

The UPM is the largest and oldest of the Spanish technical universities. It has a lecturing staff of over 3,000, around 40,000 undergraduates and approximately 8,000 postgraduates. In the style of the large French institutions, the UPM comprises 21 schools focussed on different areas of engineering. Although it could be argued that the UPM is a young institution (it was founded in 1971), many of the schools enjoy a history in excess of 200 years, as they had existed independently prior to the unification and consequent formation of the UPM. Even today the schools retain a large amount of autonomy, something that can lead to the non-existence of a strong identity of a single university.

In more specific terms, the School of Civil Engineering (which offers the Degree in Materials Engineering), is one of those with more than two centuries of history. Having a lecturing staff of around 250, it is an institution with highly traditional teaching activities; the average age of lectures is around 50 years-old, fewer than 10% of lecturers have experience in educational innovation and fewer than 30% of modules involve some degree of on-line contact with students.

In addition, within the UPM the Degree in Materials Engineering is somewhat singular, as it is an inter-centre course in which materials specialists from seven different schools of engineering across the University participate.
The objectives of the proposed methodology

The objectives encompass three strategies designed to strengthen the implementation of the Degree in Materials Engineering: Interdisciplinarity, educational innovation and internationalisation.

**Interdisciplinarity.** The project *The Engineer of 2020: Visions of Engineering in the New Century*, undertaken by the National Academy of Engineering (NAE, 2005) in the United States, affirmed that the engineer of the 21st century will essentially be of an interdisciplinary nature. Such a perspective is one shared by the authors; they believe that an inter-centre degree course such as that offered in materials engineering starts from a privileged position through involving a multidisciplinary lecturing staff, comprising lecturers from seven different schools and highly contrasting fields. The objective of the degree is to continue enriching such variety, inviting professionals from different fields to participate, as well as lecturers from other countries and different academic and professional cultures. In order to produce the interdisciplinary engineer, it is critical that lecturing staff offer a transversal vision. Nonetheless, we remain aware that working with such a varied group requires an additional effort in terms of coordination, both among lecturers and in the integration of materials. One such challenge, therefore, is undoubtedly the generation of a common working space.

**Educational innovation.** Implementation of the EHEA brought with it momentous change in teaching methodologies which, in turn, led to significant challenges for such a traditional institution as the UPM. The first initiative was to define a clear strategic position: the need for innovation in teaching. The contemporary highly dynamic nature of disciplines and professions, and continually fluctuating demand, make it vital that a permanently innovative culture to become established. How to enable methodological renewal be established across a degree course, and not to leave it to the isolated initiatives of parts of the lecturing staff, is undoubtedly one of the underlying challenges to be met (Trowler et al, 2003; Eraut, 1975, Goodson et al, 2006; NSB, 2007). Given the difficulty of changing the way of thinking of a large sector of the lecturing staff, the strategy has been to generate tools and new practices, making them available to all lecturers. In this sense, special emphasis is placed on two aspects: incorporating information technology in teaching and working on transferable skills.

**Internationalisation.** The Degree in Materials Engineering is the only undergraduate course offered at the UPM to teach all the modules of two semesters in English. This involves a strategic decision focussing on the internationalisation of undergraduate studies, in accordance with the new educational model applied at the UPM. However, an international strategy entails much more than the provision of content in the English language. Hence, the primary objective is to disseminate this offer through reaching exchange agreements with prestigious institutions based in other countries, supporting the staff participating in the initiative and seeking to generate an international environment throughout the academic year with the presence of international lecturers and students.
The tools: The Educational Innovation Group (Grupo de Innovación Educativa, GIE)

In the strategic plan designed by UPM to boost methodological renewal, one point of note is the foundation of a novel structure: Educational Innovation Groups (Grupos de Innovación Educativa, GIE). Such groups aim to foment stable associations of lecturers to provide continuity to the efforts made in educational innovation, in turn, allowing for greater reflection and self-assessment throughout the initiative.

It was considered necessary to create structures that group lecturers together, forming teams to face the process of change, which take into account the experiences of all participants with objectives shared by all. These groups usually involve lecturers who teach a single module or those who teach related modules on different degree courses.

We consider the GIE is a very useful tool to support the transformation of the educational model. However, from our point of view, it is crucial that the Group maintains the perspective of the degree course as a single unit and common project, better than focusing on a specific module.

Thus, the Educational Innovation Group for the Degree in Materials Engineering (Grupo de Innovación Educativa Grado en Ingeniería de Materiales, GIM) has been created in 2010. The objective of the GIM is to become a general structure which acts as support for methodological change and educational innovation. It also seeks to become a group that sustains continuous improvement and provides a visible dimension which recognises the efforts of the participants. It is made up of 21 lecturers and doctoral students from the Department of Materials Science. Of the GIEs at the University, the materials engineering group is the only one that includes a whole degree course within its field of action, something which allows it to work with a general perspective and have a direct impact on teaching and learning processes. The main objectives our work involves are the following:

a) To create tools, new practices and support services, generating a common working space, promoting the use of information technology (IT) for teaching and working on the development of personal skills of the students.

b) To make resources available for innovation; generating a capacity for local innovation requires infrastructure that we lack. The existence of the GIE has allowed access to basic resources which have enabled us to maintain the long-term effort needed for continuous improvement.

c) To influence the learning environment at the educational centre; this is something which is perhaps the most difficult and intangible, yet at the same time ambitious, aspect. It is vital that we transmit the existence, and the key role they have to play, of both the educational project for the future and the action plan to carry it out within the sphere of methodological renewal.
Initiatives and results

**Generating a common working space.** The creation of a satisfactory common working space for lecturing staff has been a priority. The main tool used for staff coordination has been fortnightly meetings, held midweek during the teaching year. These meetings are short, being limited to one hour at lunchtime, useful to the staff and highly participative. Given that such moments of professional communication must respond to a strategy, the content is prepared beforehand by the respective coordinators. In order to provide support in the use of technology, they are also attended by the Head of IT. During 2010-11 more than 40 such meetings have been held, which have provided the backbone to the implementation of the first two years of the degree course. It is usual for each lecturer to participate in around 10 meetings over the year; the amount of satisfaction has been extremely positive with a rating of 9/10 being highlighted by an internal survey. In 2011-12 approximately 60 meetings are foreseen; this GIE will be required to contribute a significant organisational and logistical effort.

**Supporting the development of interpersonal skills.** Work in interpersonal skills is one of the most important innovations which the Bologna Process has brought. Experience shows that lecturers value work in such skills as positive, though some reluctance does emerge when they lack the tools and, in addition, when development in this area overloads certain modules. In our opinion, the most effective way to apply these types of initiatives is "to share them" among all and enable them to be motivated, supported and guided by degree coordinators and professionals with experience in the field. Hence, this GIE has backed activities that transverse modules in order to avoid a situation in which lecturers have to work alone on developing these skills. One such transversal activity has been implemented for each academic year, in which the entire lecturing staff participates. The results have shown that such activities, in addition to their unquestionable educational usefulness, foster a "custom" of working on interpersonal skills with both students and lecturers, which is something we consider as highly important at a moment of change such as the present. The findings of an internal survey undertaken at the UPM show that the students value the teaching of interpersonal skills (at 7.48) at a similar level to theory (7.23), and a little more than practice (6.55), with the evaluation being one point higher among materials engineering students than others at the UPM (OA-UPM, 2010).

**IT initiatives:** Support has been requested and given to the lecturers for all modules to use Moodle as a student contact tool. Furthermore, measures have been applied to request students to obtain a wifi-enabled laptop computer whenever the lecturer specifies its need. This measure has been successful, both from the point of view of the lecturing staff (enabling the carrying out of IT-supported activities in lectures) and from the students (who have become "enthused" by the activity). The academic year 2011-12, as a result of an educational innovation project, will see use in materials engineering of CES EduPack software developed by the University of Cambridge. This will be rolled out, in contrasting manners, in the majority of modules and will be one factor more in the vertical and horizontal connection of the degree course.
**Initiatives oriented towards internationalisation.** Work has been undertaken in the development of international opportunities for exchange students: this has included a special portal, preparation of a publicity leaflets in English, and contact with prestigious universities in other countries. Furthermore, efforts have been made in providing support and recognition for lecturing staff who will be teaching in English: free support workshops and assistance with the translation and editing of teaching materials. Finally, the work of lecturers has been supported by inviting eminent academics from other countries to collaborate with our own team. Their presence constitutes a highly enriching educational experience both for the students (who will encounter different teaching methods) and for the lecturers (who will be able to coordinate and share experiences, teaching methods and assessment methods with academics from other cultures). The work of coordinating and including such activities throughout the academic year has been done through the GIE. In 2011-12, the third year of studies will be taught entirely in English, with 30% of students and five visiting lecturers being from other countries.

**Resources and recognition for innovation.** Recognition of the participating lecturers: Ten competitive educational innovation projects across the UPM. Also, the Educational Innovation Prize of UPM in 2011 was awarded to a member of this group. The resources obtained in these two years are around €100,000, devoted mainly to generate an innovation infrastructure financed through the educational innovation projects acquired.

**Other progress parameters:**

- Level of student satisfaction with the degree course: 8 out of 10, one of the highest in UPM (OAUPM, 2010).
- OpenCourseWare (OCW): the first three modules with OCW have been prepared within the area of materials science and metallurgical engineering.
- Student self-assessment material: 25 hours of video of authentic presentations made by the students, which can be accessed in order to carry out self- and peer-assessment.

**Conclusions**

Clifford Adelman (Adelman, 2009), of the American Institute for Higher Education Policy, argues that the Bologna Process is "the most far-reaching and ambitious reform of higher education ever undertaken". Even though it is still a work in progress, it has attracted both considerable attention and imitation all over the world, so "it has sufficient momentum to become the dominant global higher education model within the next two decades" (Adelman, 2009). The year 2010 is far from being the final deadline for the Bologna Process; rather it is the beginning of a new phase which will perhaps be the most difficult and crucial for its success. The issue is not one that questions if the foreseen changes have been undertaken, but one that considers if appropriate measures are being adopted to stabilise them over time and complete the process of not only structural but also methodological renewal.
In the view of the authors, it would be erroneous to break now but also try to continue pushing onwards with the same tools. Today we are highly conscious of educational change, although much of what we know is centred on why change fails. What we require to commence change, on many occasions, is considerably different from what we need to keep it alive.

Innovation in education is highly influenced by local conditions (such as the respective school, department or students) and the specifics of a given discipline. Therefore, ultimately, we should consider innovation as a change planned as a response to the problems we perceive at our educational centres and on our degree courses, rather than thinking of it as the introduction of a new method or methodology.

Therefore, we consider that the view of a degree course as a unit and common project is indispensable in channelling the initiatives required to improve education and learning. The generation of an environment and local capacity for innovation in the educational centres is the route to be taken in achieving general methodological renewal.

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A new teaching tool on the European space for higher education: Fusion of laboratory and research results

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Abstract: A new approach of educational methodology is presented to improve both laboratory practices in Materials Science and workshop tasks in Mechanical Manufacturing subjects. This educational experience is raised to merge two compulsory subjects in the new Mechanical Engineering Degree from University of La Rioja. The three principal objectives are as follows: 1) increase the number of students taking interest in practices, 2) eliminate the recurrence of basics concepts between different subjects in the new degree, and 3) encourage the student participation in the research work of professors involved in the mentioned disciplines. The experience is based on the development of a set of working practices in both the Materials Testing Laboratory and Manufacturing Workshop. All practices are also related to the research lines carried out by professors in these Areas of Knowledge. The groups consist of 8 students: 4 students are from the compulsory subject of Manufacturing, and the rest are from Materials Science. This educational methodology is scheduled in the next two years of the new Mechanical Engineering Degree, but we present the first results testing in a pilot study.

Introduction

The model of higher education in Spain is out-dated and has left us traditional practices that in several aspects are poorly matched to modern educational needs. The new educational model in the Spanish university (ME, 2003) is based on the establishment of the European Credit Transfer System (ECTS), the homogenization of the teachings, and the
continuous improvement in the teaching-learning system. A main objective is to achieve a more prominence role of the students in the educational model and that they take more responsibility for their own learning.

A very important part of that process is the updating of traditional practices. The chosen way for the new Mechanical Engineering Degree (MED) at the University of La Rioja (UR) is the incorporation of more dynamic and active educational methodologies into the new subjects (ME, 2005). These methodologies are mainly developed for an improvement in the quality of the practical skills acquired by students. This is a very important idea in engineering teaching, that is to say, a higher level in practical skills gives to the student higher ability to solve real problems.

This proposal is based in the fusion of practical classes of two compulsory technical subjects to create a common way of teaching. The case of study is focus in practical classes of materials testing, manufacturing works, and easy research tasks such as data collection, re-adjustment of measuring equipment, or checking results.

Professors who develop this methodology are forced to make many changes, but they also will have the feeling it will improve the “capacity of students for applying knowledge in practice” (generic competence) (Prince, 2004). Besides, the number of students interested in laboratory practices seems to be easily increased, reducing the students’ apathy. In some way, it will make the course more attractive, resulting in more motivated students and higher study yields. In the opinion of the authors, these are the main reasons why this work is important for researching in engineering education.

In summary, the main issue is to determine what level of students’ motivation (Ames&Archer, 1988) is achieved after one semester in both mentioned subjects. The initial hypothesis of work was that the interest shown by students would be higher when the method proposed in the article was applied to them, than in those cases in which traditional methods were used.

In this article we present the procedure, results and our analysis and conclusions in relation with the evaluation done by Engineering, Data Mining and Numerical Simulations (EDMANS) research group.

**Background**

In 2010 a report based on Delphi analysis was made in order to know the needs and future trends in the labour market for new undergraduates and graduates from the UR. The report states which are the three most important generic competences required for a Technical Industrial Engineer in Mechanical Engineering (TIEME) (1st cycle degree). The conclusion of the report was that the labour market is demanding training in complex problem solving abilities and practical skills whose are frequently at odds with traditional university teaching practices.
In addition, six annual reports of job-search (Figures 1 and 2) have been made to undergraduates from the UR between years 2000 and 2005. The undergraduates in TIEME have answered questions (scores: 1-5) about their opinion of the level of competences acquired through higher studies in connection with their jobs. Figure 1 shows that most of the undergraduates in TIEME answered with below-average values for competences related to practical skills. However, they answered with average values about the connection between their actual job and what they learnt during their higher studies (Figure 2). These differences about their practical skills and employability can be interpreted as "the studies are correctly designed to give them the skills they need to get a job, but there are important flaws in the teaching methods".

The results of end-semester questionnaires on the performance of the teaching faculty have also been analysed in year 2010/11. The aim is to know the motivation of students in previous years. Two specific questions were examined:

- Nº15: The professor tries to keep students interested in the subject (Score: 1 - 5 points)
• Nº 22: How much interest has this subject matter on your career? (Score: 1 - 5 points)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Year</th>
<th>Question nº 15</th>
<th>Question nº 22</th>
<th>Name of the career</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Variance</td>
<td>Mean</td>
</tr>
<tr>
<td>Global</td>
<td>2010/11</td>
<td>3.8</td>
<td>1.2</td>
<td>3.7</td>
</tr>
<tr>
<td>TIEME</td>
<td>2010/11</td>
<td>3.6</td>
<td>1.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Degree</td>
<td>2010/11</td>
<td>3.4</td>
<td>1.3</td>
<td>3.6</td>
</tr>
</tbody>
</table>

A Student’s t-Test (Cohen, 1988) has been performed to establish whether the mean value of the descriptor for the selected questions nº 15 and nº 22 are significantly different. The results show that the students enrolled in new MED are less interested in their subjects than students in other courses from UR, even in TIEME:

• The mean of question nº 22 was significantly higher in global (mean = 3.7) than in degree (mean = 3.6; t = 2.024, p = 0.0438 (two-tailed), df = 279.55).
• The mean of question nº 15 was significantly higher in global (mean = 3.8) than in degree (mean = 3.4; t = 5.894, p = 1.08e-08 (two-tailed), df = 277.45).

**Methodology**

The proposal will be implemented in two subjects of the new MED. Both subjects are in the first semester on the second year of the course. The Materials Science subject has 6 ETCS credits and Mechanical Manufacturing subject has 4.5 ETCS credits distributed in lectures and practical classes including workshops on report writing. The amount of ECTS credit points for practical classes is 3.5 and 2.5 ECTS credits respectively.

The works considered in this method consist of the following:

• Practices in materials testing laboratory (Materials Science subject),
• Practices in manufacturing workshop (Mechanical Manufacturing subject),
• Research tasks at the Department of Mechanical Engineering supervised by EDMANS group.

Even though the second year of the new MED will start in the year 2012/13, a pilot test was decided to be conducted in the second semester of the year 2010/11. The authors believed that it was a right decision testing the method in a pilot study to get experience.

The proceeding is divided into twelve practical classes for both subjects. Each practice takes four hours (two hours of each subject), so the module is comprised in total of 6 practices. These practices are also useful as checkpoints and continuous evaluation of student work. Before each practice, students will be given instructions in preparation for the report-writing workshop.

Along the semester, lecture classes have been properly scheduled to provide the theoretical parts previously to the laboratory practices. In addition supporting activities...
are also scheduled to make practical classes less difficult for students. The supporting classes will help students when there is greater complexity due to the relationship with the research line. Following table shows the fall semester schedule of practical classes (from La-1 to La-6), lecture classes (from Cl-1 to Cl-8), and the hours of supporting classes (from Tu-1 to Tu-4):

<table>
<thead>
<tr>
<th>Date</th>
<th>Week</th>
<th>Lecture (h)</th>
<th>Lab. (h)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon 05/09/11</td>
<td>1</td>
<td>2 (Cl-1)</td>
<td>0</td>
<td>Steel</td>
</tr>
<tr>
<td>Mon 09/09/11</td>
<td>2</td>
<td>1 (Tu-2)</td>
<td>2</td>
<td>Stainless steel</td>
</tr>
<tr>
<td>Mon 12/09/11</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>Polymer synthesis</td>
</tr>
<tr>
<td>Mon 16/09/11</td>
<td>4</td>
<td>2 (Cl-2)</td>
<td>3 (La-1)</td>
<td>Polymer analysis</td>
</tr>
<tr>
<td>Mon 19/09/11</td>
<td>5</td>
<td>1 (Tu-1)</td>
<td>3</td>
<td>Polymer testing</td>
</tr>
<tr>
<td>Mon 22/09/11</td>
<td>6</td>
<td>2 (Cl-3)</td>
<td>3 (La-2)</td>
<td>Ceramics</td>
</tr>
<tr>
<td>Mon 25/09/11</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>Composite materials</td>
</tr>
<tr>
<td>Mon 28/09/11</td>
<td>8</td>
<td>2 (Cl-4)</td>
<td>3 (La-3)</td>
<td>Composite analysis</td>
</tr>
<tr>
<td>Mon 30/09/11</td>
<td>9</td>
<td>0</td>
<td>3</td>
<td>Composite testing</td>
</tr>
<tr>
<td>Mon 07/10/11</td>
<td>10</td>
<td>2 (Cl-5)</td>
<td>3 (La-4)</td>
<td>Powder materials</td>
</tr>
<tr>
<td>Mon 14/10/11</td>
<td>11</td>
<td>1 (Tu-1)</td>
<td>3</td>
<td>Mechanics of corrosion</td>
</tr>
<tr>
<td>Mon 21/10/11</td>
<td>12</td>
<td>2 (Cl-6)</td>
<td>3 (La-5)</td>
<td>Corrosion testing</td>
</tr>
<tr>
<td>Mon 28/10/11</td>
<td>13</td>
<td>2 (Cl-7)</td>
<td>3</td>
<td>Mechanics of abrasion</td>
</tr>
<tr>
<td>Mon 31/10/11</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>Defects and discontinuities</td>
</tr>
<tr>
<td>Mon 07/11/11</td>
<td>15</td>
<td>2 (Cl-8)</td>
<td>2 (La-6)</td>
<td>Destructive testing</td>
</tr>
<tr>
<td>Mon 12/11/11</td>
<td>16</td>
<td>1 (Tu-4)</td>
<td>2</td>
<td>Non-destructive testing</td>
</tr>
</tbody>
</table>

**Theoretical Framework**

There are various studies on competences to consider. The ABET criteria and the results of Careers after Higher Education (CHEERS) are two works of relevance. In this study we have adopted the scope of the project “Tuning Educational Structures in Europe” (Tuning) because most of the developed initiatives on competences in Spain are based on it. These generic and subject-specific competences represent a combination of understanding, knowledge, attitudes and abilities the student has to develop during his carrier.

Only one generic competence has been considered in this study from a list of 85 different competences of the Tuning scope: “capacity for applying knowledge in practice”. This competence represents the skill to apply in practical classes, projects, or real problems the basic general knowledge obtained in the field of study. The levels of success according to the Tuning’s taxonomy are as follow:

1. Apply knowledge in practice in the specific field of study (level 1).
2. Apply knowledge in practice in wide field of study (level 2).
3. Apply efficiently knowledge in practice in different fields of study (level 3).

Besides, Students’ Evaluation of Education Quality (SEEQ) is used as a validated instrument to collect student ratings of instruction that can lead to improvement. It is composed of several items grouped into nine dimensions of teaching: learning, individual rapport, etc. A five-point scale also comprises SEEQ: strongly agree, agree, neutral, disagree, and strongly disagree. The evaluation consists of 32 compulsory questions, a limited number of demographic questions, one teacher nominated question, and two open-ended questions for student feedback.
Finally, the Likert-type scale (Linkert, 1932) is the sum of responses on several statements (Linkert items) that the student is asked to evaluate according to any objective criteria. When responding to Likert items, respondents specify their level of agreement or disagreement on a symmetric agree-disagree scale for a series of statements. This scale is the most widely used in teaching survey researches. After the research survey is completed, each item may be analysed separately.

**Participants in the Research**

The first group of participants were four professors of EDMANS research group who are highly experienced in teaching both subjects. They have worked in different areas such as Thermic Engines, Project Management, Metallurgy&Materials Science, or Manufacturing. They carried out this study without previous experience in using this new approach for practical activities. They were 2 female and 2 male professors, with one woman from each subject.

The second group of participants consisted of eighty-four undergraduate students \((N=84)\) enrolled in TIEME course at the UR. Participants included seventy males \((N=70)\) and fourteen females \((N=14)\). But not all the students were selected to complete the questionnaires. We only considered the students that had completed two previous courses in the fall semester very similar to those covered in the study. Both subjects are Materials Science \((7.5\ ETCS\ credits)\) and Machine Tools \((4.5\ ETCS\ credits)\) of the TIEME. In these subjects had been used traditional techniques for laboratory classes. The initial group of students was reduced to forty-five students \((N=45)\). Final participants listing included thirty-five males \((N=35)\) and ten females \((N=10)\).

**Procedure**

A pre-test/post-test study (Borrego, Douglas & Amelink, 2009) was conducted to assess the impact of the new methodology. Specifically, this research model involved measuring the dependent variable both before and after the treatment. The two phases of the research are as follow:

- **Phase One.** As mentioned in the previous paragraph, along the fall semester of 2011/12 traditional teaching methods were applied to Machine Tools and Materials Science subjects of the ITEM. Both subjects are taught in the same course and semester and their syllabus share some practical learning objectives. The participants completed a pre-test that measured students’ prior motivation in practical classes.

- **Phase Two.** After that, the new teaching methodology was applied to Manufacturing Engineering and Materials Testing subjects of ITEM along the spring semester of 2011/12. Both subjects share learning objectives and also practical activities. Once again, the participants completed a post-test that assessed students’ post motivation in practical classes.
Both SEEQ questionnaires contained Likert-scale items for measuring student's beliefs of how high was their motivation. The survey contained another items that will be analysed in future researches.

**Data Analysis**

Both questionnaires were given online and they were graded automatically with the Learning Content Management Systems (LCMS) of the UR (http://www.campusvirtual.unirioja.es). The students only have to click the icon for the evaluation and are off and running. These surveys are anonymous and the feedback, both numerical and written is only available to the course teacher and LCMS administrator.

Bellow, the results of information provided by both SEEQ questionnaires are presented. The participants who took both tests were thirty-four (N=34), because eleven students dropped one course:

<table>
<thead>
<tr>
<th>Group of questions</th>
<th>N</th>
<th>pre-test (h)</th>
<th>Post-test (h)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEARNING (1)</td>
<td>34</td>
<td>3.6 (1.1)</td>
<td>3.7 (1.3)</td>
<td>Finding the course stimulating</td>
</tr>
<tr>
<td>LEARNING (2)</td>
<td>34</td>
<td>3.0 (1.2)</td>
<td>3.0 (1.3)</td>
<td>Learning valuable things</td>
</tr>
<tr>
<td>LEARNING (3)</td>
<td>34</td>
<td>3.7 (1.1)</td>
<td>3.7 (1.2)</td>
<td>More interest in subject after course</td>
</tr>
<tr>
<td>OVERALL (1)</td>
<td>34</td>
<td>3.7 (1.0)</td>
<td>3.9 (1.0)</td>
<td>Comparing with other courses</td>
</tr>
</tbody>
</table>

In this case, researchers wanted to investigate differences between two surveys. There wasn’t a pre-existing theory to guide the formation of the hypothesis about relationships, and the hypothesis was formulated as: the interest shown by students would be higher when the didactic method proposed in the article is applied to them, than in those cases in which actual methods are used.

Since the dependent variable examined in the study is continuous, Student’s t-Test has been used to analyse the results. This test has been performed to establish whether the mean values of the descriptor for the selected Likert-items are significantly different, so the hypothesis can be either rejected or accepted based upon the results of the statistical analysis (Howell, 2002).

The results show the motivation of the students who are enrolled in both Manufacturing Engineering and Materials Testing subjects:

- The mean of question LEARNING (1) was not significantly higher in pre-test (mean=3.6) than in post-test (mean=3.7; t=2.039, p=0.0455 (two-tailed), df=64.85).
- The mean of question OVERALL (1) was significantly higher in pre-test (mean=3.9) than in post-test (mean=3.7; t=0.392, p=0.6963 (two-tailed), df=63.85).

Overall, the results suggest (OVERALL (1)) that the majority of students agreed that this course was significantly better than other courses they had had at UR. But they also suggest (LEARNING (1)) that they did not find the course more intellectually stimulating after the didactic method proposed in the article is applied to them.
Results and Summary

The main issue was to determine what level of students’ motivation was achieved after one semester in two subjects when the method proposed in the article was applied to them. The validity of the tests of this study was checked and results did not seem likely to lead to success of the educational proposal.

Conclusions and Recommendations

The comparison of both methods has not shown important differences. We can conclude that the application of the two described methodologies did not suppose an increase in student motivation in the both subjects. These measures contradict the conclusions based on the perceptions of the professors. In any case, the authors, who had not previous experience, think that only one semester is a very short time in using this methodology. It is even possible that this methodology alone cannot increase the motivation of students.

Some failures that have been detected in the implementation could be corrected before next course. For example, activities about destructive testing have generated overload for students. In other cases, students have exceeded the number of hours allocated for one task because of its complexity.

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Computer Adaptive Testing and the Networked Model of Curriculum in an Engineering Education Learning System (MAPI-CAT): The Case of Fourier Analysis in Mexico

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Abstract: Computer Adaptive testing and Networked Model of Curriculum are areas of Engineering Education with potential to contribute to the acquisition of complex and abstract topics such as Fourier Analysis. In the world, the United States and Serbia have invested in systems that have taken advantage of only one of each. Mexico has implemented mechanisms of engineering evaluation that afford opportunities for investing in a system of this kind. The long term contributions of such system involve the creation of a culture more centered on design, a well understood challenge in Mexican and world-wide engineering. The short term contributions involve the creation of a culture of learning and assessment more attuned with international advances in engineering education. This paper focuses on the description of the MAPI-CAT and the analysis of its short term contributions.

Introduction

Mexico has the largest engineering student population in the continent, approximately 745 thousand students. However, very few of these engineering students decide to continue their education through graduate school (approximately only 3 thousand) (ANUIES, 2008). Not surprisingly, according to Mexican Academy of Engineering, the number of patents developed is very scarce, less than a thousand between the period of 2003-2008 (Academia de Ingeniería, 2008). With such a number of engineering undergraduate students, good natural resources and a relatively large domestic market, the potential for
the country's development is vast (OECD, 2008). The proven formula of success involves the development of a strong undergraduate curriculum, including research and development, centered on engineering design.

In Mexico, a national effort conducive to the strengthening of a national curriculum involves the National Center of Evaluation for Higher Education (CENEVAL), created less than two decades ago. As its equivalent in the USA, the Educational Testing Service (ETS), CENEVAL administers the major exams for university and college selection. In addition it certifies undergraduate students of all majors via the General Examination for Bachelor's Degree Graduates (EGEL). For the EGELs, CENEVAL request professors from all universities and higher education institutes to volunteer in the creation of test items and utilizes state-of-the art psychometrics to assess the validity and reliability. However, to this point, CENEVAL has not incorporated computer adaptive versions of its exams as ETS (CENEVAL, 2011; Gago, 2008). Standardized testing in Mexico as in the rest of the world has made its way and will remain as a metric for educational policies.

On the side of design, Problem/Project Based Learning and Service Learning are two examples of lines of practice and research around the world. Both look at the practical implementations of mathematics and science concepts to solve real problems; both bringing design to the heart of the engineering experience. The Carnegie Foundation for the Advancement of Teaching’s Preparation for the Professions Program published in December of 2008 a report titled “Educating Engineers: Designing for the Future of the Field”. This report emphasizes the role of laboratory-practice and design in a model of curriculum called networked model. The networked model advocates the introduction of laboratory and design experiences as early as the first year of the engineering program. The rationale is that concepts are to be revisited for the duration of the program in order to fully mature (Sheppard et al., 2009). Figure 1 shows a schematic of the spiral learning trajectory of the networked model.

![Figure 1: Schematic of the Network Model of Curriculum. Source: Sheppard et al. (2009)](image-url)
Computer adaptive testing affords opportunities for assessing with a very good level of
detail, the proper understanding of concepts. It also affords opportunities for more
appropriate and individualized learning via the assignment of specific lessons. It lends
itself for implementation of the spiral trajectory of learning by presenting different levels
of the same concept in design context scenarios. As a practice tool, it also familiarizes
students with standardized testing allowing them to have a more interactive tool for
evaluating their own progress. Instructors also benefit from it by devoting less time to
grade assignments and more time to prepare design experiences.

For the purpose of advancing the development of engineering in Mexico, a group of four
Mexican institutions are developing an engineering learning system called MAPI-CAT. The
MAPI-CAT incorporates the networked model of curriculum and implements item
response theory (IRT) and computer adaptive testing (CAT) in the evaluation of students’
knowledge.

**Background (Lit. Review)**

The networked model of curriculum has its basis in the spiral curriculum. Within the
engineering education community, chemical engineering is the pioneer in the use of spiral
curriculum. Dixon, Clark, and DiBiasio (2000) report the results for sophomore chemical
engineering students in the Worcester Polytechnic Institute. After two years of
implementation, one of the most relevant findings involved the observation of students
during competitions. According to the authors, spiral–taught students behaved more than
practicing chemical engineers than their classical-taught chemical engineering
counterparts.

At Virginia Tech, Balasubramanian et al. (2011) developed a nanotechnology freshman
module based on the spiral curriculum. The assessment included a survey which questions
identified changes in attitude towards nanotechnology. The questions were related to
motivation to pursue a nanotechnology minor or if nanotechnology relevance was
perceived in the intended major. In addition, misconceptions were identified via pre- and
post-tests of learning outcomes, which were properly addressed during the module.

On the side of computer adaptive testing, Markovic et al. (2011) implemented a distance
learning system using computer adaptive testing for computer engineering majors.
According to the authors, the computer adaptive piece was perceived as positive by users
and its impact was substantiated by the passing rate of students who used it. It is worth
clarifying that the “adaptive” characteristic of interest is the one used in psychometrics,
which is based on Item Response Theory. Other “adaptive” systems are being developed
using intelligent tutoring, but those are not aligned with standardized testing, as it is the
case of ETS or CENEVAL, and are not the topic of this project.

**Purpose and Research Questions**

Capitalizing on the networked model of curriculum as well as advances in psychometric
and computer aided instruction; an engineering education computer system called the
MAPI-CAT was developed by four Mexican institutions. The purpose of the MAPI-CAT is to
contribute in the acquisition of complex and abstract concepts. Currently, the MAPI-CAT is concentrated in advanced mathematics, specifically Fourier analysis. The research questions of the project are as follows:

1. How is the Networked Model of Curriculum in the MAPI-CAT contributing to the acquisition of complex and abstract concepts such as Fourier Analysis in Mexico?
2. How is the Computer Adaptive Testing in the MAPI-CAT contributing to the acquisition of complex and abstract concepts such as Fourier Analysis in Mexico?

Implementation of the MAPI-CAT

The stages of development of the MAPI-CAT are depicted in Figure 2. The first quarter of the project has been devoted to the analysis of curriculum for the spiral learning trajectory, the choice of the advanced mathematics course –Fourier Analysis-, and the development of test items. The second quarter has consisted of the calibration of tests items and the implementation of the Computer Adaptive Test. The third quarter is the development of the instructional module and its integration to the MAPI-CAT system.

The development/implementation team, spread across two Mexican states and one American state, have met virtually once a week for a period of 8 months. During this period of time, Engineering and Computer Faculty have worked on stages 1 and 2 of the project. One hundred items have been developed and have been divided into 10 questionnaires for calibration. The system is at this point collecting responses from students, figures 3 and 4 show the interface system responsible of collecting these responses.
Methodology

Each phase of the implementation of the MAPI-CAT involves different populations. Stages 1 and 2 (first and second quarters) involve the developers of the system, faculty and research assistants as well as the students who are calibrating the items. Stage 3 involves
faculty and research assistants as well as students using the system. Since learning entitles the changes in intellectual skills, attitudes, or psychomotor skills (Gagné, 1985), and the research questions have an explorative approach to the contribution of the MAPI-CAT; the proposed assessment involves surveys, interviews, observations and comparisons of grades/performance between users and nonusers of the MAPI-CAT. Figure 5 is a schematic of the assessment methodology. Qualitative and quantitative research is underway for all involved populations.

Findings

Through embedded questions to the calibrating questionnaires and interviews with the developers of the system, preliminary findings indicate that a new approach to curriculum and assessment are getting into the culture of the institutions involved. There is no evidence of computer adaptive testing or networked curriculum occurring in the country at the moment. Great interest has generated the psychometric approaches and faculty had expressed interest in developing other modules for courses and topics such as differential equations. The MAPI-CAT is a work in progress and data collection is still occurring at the phases of development. It is expected to have more evidence of the impact of the MAPI-CAT by the end of the summer of 2011.

It is anticipated that the MAPI-CAT will contribute to the understanding of students’ acquisition of complex and abstract concepts because of the proven success of adaptive testing and spiral learning trajectory. Researchers are very interested in presenting the progress of the MAPI-CAT in the 2011 Research in Engineering Education Symposium in order to obtain informed feedback and for the purpose of stimulating discussion that could generate recommendations for research and practice.
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Virtual 3D Support Contents Oriented to Interactive Self-Learning

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Abstract: In the educational project described in this paper, new virtual 3D didactical contents have been developed to achieve specific outcomes, within the frame of a new methodology oriented to objectives of the European Higher Education Area directives. The motivation of the project was to serve as a new assessment method, to create a link between new programs of study with the older ones. In this project, new rubrics have been developed to be employed as an objective method of evaluation of specific and transversal outcomes, to accomplish the certification criteria of institutions like ABET (Accreditation Board for Engineering and Technology).

Introduction

Currently, students of the Mechanical Engineering program in ETSII-UPM (Escuela Tecnica Superior de Ingenieros Industriales – Universidad Politecnica de Madrid), develop main part of their class-work in accordance with the European Space for Higher Education (ESHE) principles [1]. The application of innovation initiatives based, for instance, in Project Based Learning (PBL), together with the implementation of new methodologies as collaborative team work and the employment of Information Technologies, have contributed to the improvement of specific outcomes, as it is established in ESHE directives. However, some deficiencies have been detected, particularly related with outcomes assessment [2].

In the project described in this paper, two aspects have been introduced to improve the observed deficiencies. First, new virtual contents have been created in PDF format with three-dimensional models enrichment [3-5]. Second, new rubrics for outcomes assessment have been developed and applied [6,7]. The main objective of the project is centred in demonstrating the viability of the new methodology for the transition to the new ESHE programs.

Methodology

The project has been developed in the subject “Design and Manufacturing in Plastics”. This subject is imparted in the 10th semester of the current program at ETSII-UPM. Two outcomes were selected, one specific “Ability to use techniques, procedures and modern engineering tools necessary for engineering practice”, which is in ABET (Accreditation Board for Engineering and Technology) outcomes accreditation list [2,8]. This institution has recently certified titles imparted on ETSII-UPM. The other selected outcome has been “Creativity”, which represents an innovative point of view, because it is still moderately
considered in engineering education institutions. Creativity is a learning outcome for the Universidad Politecnica de Madrid (UPM).

**Preliminary Study**

Students made a preliminary test to evaluate the previous knowledge in relation with the specific outcome; four blocks were evaluated with different amount of questions:

- Plastic parts validation in terms of manufacturability by injection molding process
- Mold size estimation
- Mold sub-systems pre-design
- Workshop manufacturing documentation

Initial test results demonstrated that more than a 50% does not respond correctly to the different blocks separately, what clearly identifies a weak in the outcome achievement. In the following the procedure to improve the outcome achievement will be described.

**Virtual 3D didactical support**

A combined method for knowledge development has been employed in the area of injection moulding design. Five additional sessions of class were imparted; the classes were supported with the employment of self-learning three-dimensional (3D) files, in Adobe PDF format. Usually, theoretical information for Injection Mould design is represented in classical two-dimensional (2D) cross-section views. Figure 1 depicts a core-cooling device 2D representation as usually is shown in workshop documentation.

![Core-cooling device representation](image)

Figure 1: Core-cooling device representation

However this kind of representation is difficult to understand for the student without previous background, and has to be complemented with the 3D representation that could be found in the Acrobat files made for this subject as it is shown in Figure 2.
Students can interact with the 3D representation, and obtain the most suitable view of details to understand the component functionality. Students can zoom, pan or rotate the 3D models. This type of file also supports layer visibility, video and animation possibilities. They only need acrobat reader 8.0 or higher so they are independent of the web browser.

**Student assignments**

During the development of the subject, students have to accomplish weekly personal assignments that can be described as follows:

**Assignment 1**

*Manufacturability*. The student should justify the selected part geometry to be injected, providing the design phase information, and carrying out a manufacturability study to verify the gate location, moulding window, confidence of filling, cooling quality, sink marks and air traps predictions.

**Assignment 2**

*Mould size estimation*. The student should determine the number of cavities and the proper injection moulding machine size to employ. With a cycle time estimation and applying economical data, as lot size, mould initial cost and maintenance cost, together with part weight and part surface, a detailed estimation of optimal number of cavities can be done.
Assignment 3

Conceptual mould design. The student should design a preliminary creative solution for the injection mould, providing a 2D cross-sectional view of the conceptual mould where can be identified the feeding, ejection and refrigeration systems adopted for the mould.

Assignment 4

Final validation of proposed solution. The student should carry out a multicavity analysis to cover the following aspects in the design proposal:

1. Feeding system validation. Creation of a feeding system to make a preliminary study of runner and gates, runner balance and runner optimization.
2. Refrigeration system design optimization in terms of cycle time and cooling quality
3. Cycle time optimization and quality prediction with a study of filling and packing, adjusting the packing profile, and analyzing the shrinkage and warpage in injected components

Project Based Learning

Last part in course consists in a project oriented collaborative work, to develop the detailed design in the injection mould. The students form groups of three people that will collaborate in the 3D complete design of core and cavity of the mould, and normalized components selection for a production kit. The work could be divided in three phases:

1. Three-dimensional design of core and cavity of the mould (assessment of the use the CAD tools, number of solutions and originality criteria)
2. Normalized components selection and integration (viability criteria)
3. Manufacturing workshop documentation generation

With this work we can evaluate the achievement in the use of CAD tools as part of the ABET outcome. They have to design the mould using a 3D CAD program of their choice.

For the development of the creativity, additional information has been thought to students. They have learnt basic creativity techniques, and specially brainstorming in a one hour session. The assessment of this achievement has been done using a rubric with two performance criteria: number of solutions, originality and viability.
Results

Table I shows the comparative results of the initial vs. final outcome assessments. The figures represent the percentage of the mean value of correct answers on each block of questions, associated with their correspondent rubric indicator. From these data can be deduced the following conclusions:

1. There is a significant improvement over all the indicators
2. Improvements in indicators “Design validation” and “Detailed Design”, although remain significant, are not very remarkable and can be due to the practical work developed in the subject. On the other hand, these indicators measure abilities that are not exclusively developed in this topic.
3. The improvements obtained in “Conceptual Design” and “Pre-Design” highlight the success of the introduced methodology, and they are the abilities more specific for the outcome considered. The results obtained support that use of active learning techniques improves the outcome achievement in students.

<table>
<thead>
<tr>
<th>Rubric Indicator</th>
<th>Initial Test</th>
<th>Final Test</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Validation</td>
<td>36</td>
<td>42</td>
<td>6</td>
</tr>
<tr>
<td>Conceptual Design</td>
<td>32,33</td>
<td>56,1</td>
<td>23,77</td>
</tr>
<tr>
<td>Pre-Design</td>
<td>36</td>
<td>78</td>
<td>42</td>
</tr>
<tr>
<td>Detailed Design</td>
<td>41</td>
<td>48</td>
<td>7</td>
</tr>
</tbody>
</table>

Table I: Performance results for the specific outcome “Design of Moulds”

Conclusions

In the project described on this paper, a new methodology has been applied in order to get an outcome improvement on students. For the first phase of it, an important amount of virtual 3D didactical support material has been developed. The overall objective has been to adapt the programs of study to the new directives of ESHE, but what is more important
to highlight the usability and efficiency for student formation. New rubrics have been also developed for the objective assessment of the outcomes, to fulfil the evaluation criteria of institutions like ABET that certifies programs of studies in engineering universities.

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Juan J. Marquez et al., Virtual 3D Support Contents Oriented to Interactive Self-Learning


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Want to Change Learning Culture: Provide the Opportunity.

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Abstract: Many students resist having to take responsibility for their own learning rather expecting this to be the responsibility of their teaching academics. This resistance is often associated with Asian cultures where there is a perception of reliance on rote learning and passively being taught. Furthermore, undertaking collaborative activities may be more difficult when students are not being taught in their primary language.

While teaching an undergraduate engineering science program in Hong Kong the authors had initially found it difficult to motivate students to actively participate in their learning. In response, learning activities were redesigned to promote a culture of learning rather than a focus on passing a series of assessments.

We found that despite some initial apprehension students enthusiastically engaged in collaborative learning when given the opportunity. Furthermore, formative activities freed students from the burden of strategically collecting marks, allowing them to focus on learning, enjoy the activities and take responsibility for their own progress.

Introduction

Engineers are often required to make critical judgements involving decisions that extend beyond traditional discipline boundaries. This requires professional engineers to undertake ongoing learning. Much of this learning is informal, learnt on the job from peers from different disciplines (Trevelyan 2007). Hence, to prepare students for professional practice they require opportunities to experience, practise, reflect and improve their ability to work in collaborative learning environments.

Many students resist having to take responsibility for their own learning rather expecting this to be the responsibility of their teaching academics. This resistance has often been associated with Asian cultures where there is a perception of reliance on rote learning and an expectation of being passively taught. These tendencies may be a result of students previous educational experience that often combined didactic teaching and passive
learning. Furthermore, these tendencies may be compounded by academics’ believing that students have a preference for passive rote learning, structuring their teaching and assessment accordingly (Kember 2000).

Kember (2000) uses evidence from over 90 action research projects to disprove the common assertion that Asian students prefer passive learning and resist teaching innovation. While undertaking collaborative activities may be more difficult when students are not being taught in their primary language, Kember reports that students will adjust and engage in collaborative learning activities if given the opportunity.

The University of Technology, Sydney teaches an undergraduate engineering science program in Hong Kong, where subjects are delivered in block mode. Students have typically undertaken previous engineering studies often at a local polytechnic. The authors had found it initially difficult to motivate students to participate in collaborative learning activities and in particular those that involved them using their own judgement or critical analysis. In this paper, we discuss the results from an evolutionary research investigation examining the effectiveness of integrated collaborative peer learning activities to address this issue.

**Background**

A number of researchers and government-sponsored reports (Hargreaves (1997), Jones (2003) Markes (2006), & Chung et al (2008)) discuss a gap between skills typically developed in engineering education and a range of skills required for professional practice such as communication, critical thinking, leadership, teamwork skills and life long learning capabilities. This requires not only considering what is taught but how it is taught (Hargreaves, 1997). Workplace learning and certainly practice is often collaborative (Littlejohn, Margaryan & Milligan (2009). It follows that students’ preparation for entering this environment should include opportunities to practise collaborative learning with their peers.

Collaborative learning is also attractive from the perspective of the constructivist model of learning (Jawitz and Case, 2009). Hagstrom (2006) argues that "...contexts for new knowledge construction include a blending of people ... that gives rise to differences in interpretation and provides the occasion for the construction of new knowledge....If educators simply tell students what they need to know, they encourage reliance on memorization of facts. For students to make cognitive changes, the learning experience must begin with each student becoming aware of his or her own present understanding" (Hagstrom, 2006, p28). Dana (2007) reports that compared to traditional competitive or individualistic learning environments, benefits of collaborative tasks such as small group or team based learning include higher student achievement, greater use of higher level reasoning and critical thinking skills, more positive attitudes toward the subject matter and satisfaction with the class, and better interpersonal relationships among students and between students and instructor.

While few would argue the benefits of collaborative learning these benefits are not automatic. Thoughtful design including scaffolding to motivate desired approaches and
behaviour is required. Many students have suffered through poorly designed and managed collaborative activities as articulated by the following student comment: “I've attended tutorials with tutors ... telling students to form groups and discuss the readings. ... Hearing other students' views on topics they don't understand results in zero learning.” (Stevens 2011).

The subject Design Fundamentals taught in Hong Kong was chosen as the vehicle to conduct the reported trials as students had previously had difficulty with the subject material that required them to apply critical thinking and judgement. In 2008 we redesigned the subject using collaborative learning to enhance critical thinking in line with the previously mentioned studies. A secondary aim was to promote a culture of learning in students as opposed to focusing on passing a series of assessment activities. Care was taken to design collaborative activities that encourage students to be ‘engagers’ (focused on achieving a better understanding of the subject material) rather than avoiders (focused on minimising the amount of work individual students had to do) (Yan 1996). The subject has two summative assessment components: a collaborative multistage design project and summative exam/quizzes each worth 50%. The lectures are delivered in a block mode over four consecutive days. While changes were made to both the project, method of summative assessment and the in-class activities in this paper we mainly restrict our discussion to the latter.

To investigate the effects of including collaborative learning activities in 1st semester 2010 we conducted the first cycle of the research reported in this paper (Willey & Gardner 2010). In this semester students were encouraged to test their understanding through interactive collaborative tutorial problem solving on large sheets of paper. Groups then reported to each other, discussing each other’s solutions and approach. The teaching academic then discussed the topic, addressed any outstanding issues and introduce the students to further activities requiring higher level engagement and understanding. Subsequently students tested their knowledge on each topic through a series of summative quizzes that were initially taken individually and then collaboratively using the Immediate Feedback Assessment Technique (IF-AT) cards (http://www.epsteineducation.com/home). The end of session summative assessment was achieved through the combination of an individual followed by a collaborative examination.

While most students reported higher engagement, understanding and increased ability to demonstrate the subject learning outcomes we found that some students could only demonstrate this understanding in a collaborative environment. That is, these students appeared to have what we termed “collective ability”. As part of the collaborative team they were strong contributors who appeared to understand the subject learning outcomes. However, without the support of their peers, gaps in their understanding became evident. Often groups containing these students were characterised by the group exam mark being considerably higher than the best individual mark achieved by the group members. On closer investigation, we theorised that this phenomenon had two main components. Firstly, the complex tutorial problems were mostly solved collaboratively hence not necessarily providing students with the opportunity to recognise the gaps in their own
individual learning. Secondly, the quizzes generally did not contain problems as complex as those in the final exam and hence did not afford the students the opportunity to test their higher level knowledge.

In response to these findings in the second cycle in 2nd semester 2010 the summative quizzes were replaced them with a number of in-class formative assessments. We chose to make these assessments formative as we wanted students to focus on using these activities to push their learning boundaries, make mistakes, identify gaps in their learning and have these addressed by their peers and if necessary the teaching academic. Often with summative tasks students approach them, with some justification, strategically to achieve the best mark at the expense of learning (eg they may choose to divide up work, or move on without having their knowledge gaps addressed to save time).

The formative assessment was conducted after the previously described collaborative tutorials. The assessment consisted of a series of complex problems (one covering each of the six major topics) that were typically harder than they would encounter in their final examination. After an initial attempt to solve these problems independently, students were encouraged to use their course notes and other material to solve them. They were instructed to use the exercises to identify gaps in their understanding/learning. At the end of each day students’ were encouraged to go home and study to address these learning gaps. On the following day students formed into groups and repeated the exercises collaboratively. The aim of the group was to not only answer the questions but to particularly focus on helping team members address their learning gaps. Finally, the course instructor led a discussion to resolve any outstanding issues.

While student learning improved as suggested by their grades (figure 1), a close inspection of their final examination work booklets revealed that the change had not fully addressed the issue of “collective ability”. Again we are able to identify areas where students appeared in the collaborative activities to have in-depth understanding but were unable to demonstrate this individually. Students did however report that introducing them to harder more complex problems earlier in the subject provided a strong foundation for learning enabling them to recognise learning gaps that may not have been identified if simple less complex problems had been undertaken.

After discussing this problem with students we identified two issues. Firstly, being a design subject problems are often open-ended, context dependant with multiple solutions. It is not easy for students to find problems to help them learn without some sort of discourse and feedback to discover the strengths and weaknesses of their answers. Secondly, while we had given students an opportunity to identify and address gaps in their learning, we had not provided them with a subsequent opportunity to test their learning before the final exam. One could argue that this is the students’ responsibility but given both the compressed nature of the block mode delivery and the required feedback discourse previously described we believe we needed to do more to assist students with this process (Willey and Gardner 2011).
In this paper we report on the effectiveness of changes to the collaborative peer learning process to address the issue of “collective ability”, and determine the willingness of students (in this case Asian students) to engage in collaborative learning.

Method

In 1st semester 2011 we decided to expand the collaborative learning activities by redesigning the interactive collaborative tutorials to include at least three complex problems in different contexts for each of the six major topics in the subject. Students again went through the learning cycle of first attempting the problems independently, then using their course notes, then collaboratively in groups, concluding with the course instructor leading a discussion to resolve any outstanding issues and introduce questions that expanded the problem and tested students’ understanding. There was a deliberate focus on students using these activities to identify gaps in their understanding/learning and having them addressed by their peers. Students were constantly reminded that “mistakes compress learning” and that if they are not making mistakes then they are not discovering what they do not know.

Students then repeated the process with another problem that applied the learnt principles in a different context. To make class time available for this iterative learning approach we had students complete more pre-work outside of class. Mazur uses a similar approach in his Peer Instruction methods (Crouch & Mazur (2001)) however, here we use more complex problems, take more time and reapply the principles in a different context.

These activities were followed by a formative assessment on each of the six major topics. Students initially completed these assessments individually (under formal exam conditions, closed book, separate desks etc) and then collaboratively. Again, we chose to make these assessments formative as we wanted students to focus on learning. Hence, in summary the process consisted of:

1. Collaborative tutorials: at least three complex problems on each topic set in different contexts that students attempted initially individually then subsequently collaboratively.
2. Formative assessment conducted individually under exam conditions then collaboratively
3. Final summative examination

We theorised this approach would address the “collective ability” problem by allowing students to individual test their ability in different contexts after each collaborative activity. Then subsequently have any rediscovered or newly identified learning gaps addressed by their peers. During each stage of the formative assessments students were asked to keep a record of how many times they realised they did not understand something and how often these issues were addressed by the explanations of their peers.

Additionally these activities were evaluated using a combination of a survey instrument, focus group, observations and video analysis. The survey instruments containing a series of simple answer and free response questions. Attention was paid to writing low-inference
questions. Students were handed the first survey instrument at the start of the subject which they completed throughout the activities. The second survey was completed at the end of the block mode after the final examination. The focus groups were conducted by two independent research assistants. Both had previously tutored the subject in Australia but were not involved with the subject in Hong Kong. The assistants had an opportunity to read the survey responses before the focus groups enabling them to explore in more detail the most common issues. One of these assistants was present and made observations throughout the entire block mode.

**Results / Discussion**

The class consisted of 14 students all of whom volunteered to participate in the study in accordance with the conditions required for ethics approval (to remain anonymous etc).

The collaborative tutorials provided students with the opportunity to work through at least three complex problems on each of the six major topics before attempting their formative assessment. Despite this, students still reported identifying gaps in their learning (on average 58% 1 or 2 gaps, 15% 3 or more gaps) when undertaking the formative assessments individually and discovering even more gaps in their learning (on average 54% 1 or 2 gaps, 10% 3 or more gaps) when undertaking them collaboratively. These results reflect that as students understanding improved the more they realised they did not know. Perhaps more importantly, as a result of their peers explanations most students reported having nearly all of these gaps addressed.

Students commented that while this approach initially made them nervous (being different from the more passive class experience than they were used to) it changed the way they learnt and they were genuinely excited about focusing their efforts on learning rather than the final exam.

"I would prefer to learn something that I don't fully understand rather than get a good mark without learning anything" (student free response comment).

When asked to compare their previous experience in other subjects respondents reported that in their opinion the collaborative approach significantly improved their understanding, learning experience and the amount they learnt. Furthermore, on average respondents attributed the majority of this increased learning to talking to their peers in groups.

Students reported being focused on addressing gaps in their learning as opposed to their previous tendency to focus on getting the right answer. Commenting that collaborative learning "changed how I learn" and being "surprised how much I learnt". The high engagement supports Kember’s (2000) finding that students including those from Asia will adjust and enthusiastically engage in collaborative learning if given the opportunity. However, in the author’s opinion to get the best results one must ensure that the summative assessment activities encourage such engagement. For example, in the reported trial all respondents agreed that to do well in the subject they had to understand
the concepts rather than memorising methods and that participation in the collaborative activities was good preparation for their exam.

When asked how the collaborative activities helped their learning students reported, “the brainstorming” in the groups “helped reduce ... gaps”, “my group members helped me to solve what I don't understand”(sic) and I improved my learning by “listening to the other team members ...explanation”. Students reported that most of the time group members had different levels of understanding on different topics, enabling them to move from being a teacher to being taught. Furthermore, frequently students “understood something in a different way” enabling group members to reach a deeper understanding of the subject material by being able to explain something from more than one perspective.

Numerous students commented that the collaborative activities gave them an opportunity to discuss their understanding in their own language. This in turn identified areas of comprehension that needed to be clarified by the instructor. A number of students reported that they would have liked an additional opportunity to discuss these problems with their peers after the instructor had “closed the loop” to confirm their understanding.

Our decision to make the assessment activities formative was supported by approximately two thirds of the students agreeing that if the activities had been summative it would have changed their approach from focusing on “addressing gaps in our learning to getting the right answer”. Others said “it would put us under pressure to agree on an answer” rather than finding out where our opinions and understanding differed. Several students reported that being formative allowed them “to enjoy the activities and concentrate on learning”.

While not a definitive measure a comparison of individual exam results for the three reported cycles shows an increasing trend in student achievement (see figure 1, Z unsatisfactory, P Pass, C Credit, D Distinction, HD High Distinction). This supports the evidence from our observations, student opinions and examination of student work booklets that students were more capable of demonstrating the subject learning outcomes.
individually. Hence, the combination of iterative collaborative learning activities and formative assessments successfully addressed the issue of "collective ability".

While students were mostly positive about the reported changes, there were some complaints about the collaborative activities, the most common being:

- students would have liked "more class time for collaborative activities"
- on occasions no one in their group was confident they understood a particular issue so they were unsure of the correct answer until the discussion with the instructor
- and "sometimes I learnt the wrong thing from my team members"

**Future Directions**

In the next cycle of this study we will increase the pre-class activities and further integrate collaboration by sharing anonymously online student’s answers and explanations to a series of introductory questions on each topic. This will enable more class time to be devoted to collaborative activities.

**Conclusion**

The formative assessments and associated collaborative activities were successful in addressing the issue of "collective ability", promoting higher engagement, understanding and increased student’s ability to demonstrate the subject learning outcomes. Furthermore, the formative nature of the activities freed students from the burden of strategically collecting marks, allowing them to focus on learning and enjoy the activities. We found that despite some initial apprehension students enthusiastically engaged in collaborative learning activities. Our findings support Kember’s that students including those from Asia will adjust and enthusiastically engage in collaborative learning if given the opportunity.

**References**


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Are we accidentally misleading students about engineering practice?

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Abstract: Educators who identify themselves as engineers see engineering practice in terms of the engineering they ‘perform’. Depending on their background and interests, they may see themselves in the engineering science, design, or management systems movements as observed by Rosalind Williams. Texts written by and for engineering educators help to reveal their ideas of practice. Content analysis of five major texts from a perspective shaped by extensive ethnographic investigations of engineering practice leads to a detailed description of the difference between an academic setting and a commercial setting in which most graduates seek their careers. Many important aspects of commercial practice are either missing from the texts, or are portrayed in a way that could mislead students. This paper discusses two aspects of difference: uncertain information in engineering and the connection between engineering and economic value. This analysis, with further work, could help with the design of authentic learning experiences to help engineering students to bridge the gap between theory and practice more easily.

Educators’ notions of engineering

Engineering practice is a generalized concept embracing the daily work of engineers: the term praxis captures the essence. For the purpose of this paper, engineers are people for whom their primary occupational identity concerns an aspect of engineering.

Engineering educators, who help young people construct their identity as engineers through university or college education, practice engineering just as much as engineers who work in different settings: consultancies, manufacturers, construction firms, transport enterprises, defence forces etc. Difficulties arise, however, for the majority of their graduates who emerge from university or college and practice in a different setting. When graduates experience engineering as practiced in most industries other than research and education, they can feel disoriented. “When I started, I felt completely unable to do anything useful,” one graduate reported to the author recently. Martin and her colleagues (2005) described how graduates found they were not well prepared to work with other people and lacked practical skills, factors widely reported in many other similar studies (e.g. Spinks, Silburn, & Birchall, 2007). In Australia, most companies assert that it takes up to 3 years for a novice engineer to become reasonably productive in a commercial context. This paper addresses the transition into industrial practice: an experience that can be disconcerting for many novices and employers alike.

While many would argue that a university education should not be constrained by the training requirements of a particular profession, such as engineering, most educators would like their students to experience a successful start in their chosen careers. Medical
Educators have embraced extensive clinical practice and situate themselves in, or close to teaching hospitals to promote the successful transfer of academic learning to practice. On the other hand, engineering educators have to prepare their students for a much greater diversity of career settings, and real engineering settings are often too large, expensive or hazardous to accommodate within a teaching institution. Therefore, the authenticity of learning experiences will strongly influence the transition into practice for most graduates. This authenticity will depend, to a large extent, on the ability of educators to design authentic learning tasks.

In the ethnographies by Stevens and his colleagues looking at engineering educators (2008), and by Tonso looking at student teams (2006), we can see how engineering education shapes the ‘accountable disciplinary knowledge’, skills, values attitudes and identities as students grow into “engineering”. Educators assume the responsibility for appropriately shaping this developmental process, and their notions of engineering practice can have a profound effect on their students’ beliefs.

Educators subscribe to divergent notions of engineering practice, shaped by their own pathways and experiences. Reporting an ethnographic study in an American mechanical engineering department, Quinlan described how ‘design division’ faculty saw engineering as a creative discipline through which new products are developed, whereas other faculty saw engineering in terms of developing scientifically validated theories and knowledge. She described how these different views shaped their teaching, disputes on education priorities, and hence the experiences of students in their classes. Sheppard and her colleagues (2006) provided further insights in a study that explored perceptions of about 300 faculty and students based on semi-structured interviews and focus groups in seven major American universities. These perceptions centred on problem solving based on expert theoretical and contextual knowledge, supported by a combination of formal processes and creativity.

Pawley (2009) reviewed a series of reflections on the nature of engineering and engineering beliefs among the engineering education research community between 2005 and 2007. In an ethnographic study based on extensive interviews in an American engineering school, she found that engineering faculty valued different ideas and conclusions and that calls to reshape the discipline were unlikely to influence their teaching (p309). She perceived three ‘universalized disciplinary narratives’: engineering as applied science and mathematics, engineering as solving problems, and engineering as making things. She questioned whether calls to “Change the Conversation” about engineering (National Academy of Engineering, 2008) would have any impact unless faculty share the messages with students and model new behaviours. Williams (2003) distinguished three diverging movements within academies: engineering science, design, and management systems, the latter two nourished from pragmatic commercial interests.

In leading contemporary engineering schools there is often an overwhelming representation of engineering technology and science researchers among the faculty. Quinlan’s observation that many faculty see engineering in terms of “scientific process of developing new theories from which the viability of new designs can be tested” reflects
the research identity that characterises these schools. In other words, engineering faculty subscribe to a generalised view of engineering expressed in terms of the engineering that they practice themselves.

Many students graduating from engineering schools soon encounter a very different world when they start working in a commercial or defence-related engineering environment. The difference would probably be just as great had they been educated in a commercial context and arrived for work in a research institute. Recent studies have clarified some of the differences (e.g. Anderson, Courter, McGlamery, Nathans-Kelly, & Nicometo, 2010; Domal, 2010; Faulkner, 2007; Korte, Sheppard, & Jordan, 2008; Trevelyan, 2007, 2010; Vinck, 2003). Differences between engineering practice and students’ educational experiences have provided a recurring theme in recent engineering education debates.

The relative scarcity of systematic research on engineering practice (Barley, 2005; Trevelyan & Tilli, 2007) makes it difficult for educators who would like to design learning experiences to enable their graduates to manage the transition into commercial engineering contexts more easily. However, it has not been easy to sustain engineering practice research in institutions where the dominant research discourse is engineering science, as engineering education researchers are all too well aware. Employing faculty with substantial industry experience is one way to promote authentic learning experiences. This is not easy to sustain, however, in a research-led university where research output and grants are the main measure of career success. More recently, pedagogies such as inquiry-based learning, problem-based learning and project-based learning have been advocated for research-led universities to help students develop attributes and thinking styles more appropriate for industrial practice (Kolmos & Trevelyan, 2010; Savin-Baden, 2007).

**Texts**

Texts can play a significant part in shaping faculty perceptions about engineering practice, particularly for faculty who work in predominantly teaching institutions educating a larger proportion of the world’s engineers. Texts also encapsulate notions of engineering practice held by the authors, so texts written by engineering faculty provide a further means to discern the ideas that shape students’ notions of practice.

This paper presents an analysis of five major texts using a framework derived from ethnographic research studies of engineering practice (Trevelyan, 2010).

This study grew out of two fortuitous coincidences. The first arose because the author is contributing to a major curriculum redesign (Trevelyan, Baillie, MacNish, & Fernando, 2010). The new curriculum requires the use of one or more cross-disciplinary introductory texts in an integrated foundation course for all engineering disciplines.

The second coincidence was an on-going research investigation of novice engineers (1-5 years experience) in a consultancy firm. The company management were interested to understand some of the reasons for dissatisfaction expressed by some of their clients. One of the questions included in the semi-structured research interviews was framed around
participants’ recent work for the firm. All the participants were contributing to reports
detailing technical analysis on aspects of clients’ plant and equipment. “Please tell us how
your work for this report has provided value for your client.” Surprisingly, none of the
participants could provide a coherent explanation, beyond the notion that clients wanted
to pay for the least number of billable hours needed to complete the work. One participant,
after a long pause, responded “Hmm, that’s a good question. Solve problems? Make things
more efficient, I suppose.” Another replied “I guess the value of my work is getting results
from the field.”

This observation led to more exploratory questions with engineers in different firms, all
confirming that it was difficult for them to articulate the value of their work for clients,
even for more experienced engineers. While several other interesting “gaps” or
misconceptions about aspects of engineering practice emerged from this investigation, the
absence of any clear understanding about the value contributed by their work stood out
from the rest. Young doctors have few doubts about the value of their work: saving lives
and restoring people to health has obvious value. It was puzzling that young engineers had
such difficulty explaining why their work could be valuable.

This observation, with others, provided a set of issues to frame the analysis of the texts.
Passages from each of the selected texts addressing aspects of engineering practice were
compared with evidence on engineering practice collected in the contributing
ethnographic studies. In several instances, there was no relevant material in the texts. In
other instances, the texts contributed only part of the picture, leaving other parts unstated,
suggesting fundamental "hidden" and explicit assumptions in the texts that conflict with
research evidence on engineering practice.

The five texts comprise two multi-disciplinary comprehensive introductory texts for
foundation studies in engineering, two texts on professional engineering practice intended
to complement conventional technical disciplinary courses, and a recent detailed
prescriptive text on engineering education design.

1. Holzapple and Reece’s comprehensive text (2003) is framed in terms of
engineering accounting, a teaching approach that casts the conservation laws (e.g.,
energy, mass) as simple "accounting" procedures, a unifying concept that
facilitates problem-solving in all engineering disciplines. The book was intended to
provide first year students with a "solid foundation" for the future coursework. It
provides an overview of the engineering profession, introduces engineering skills,
and describes fundamental engineering topics, such as thermodynamics, rate
processes and Newton’s laws.

2. Brockman’s text (2009) was inspired by the National Academy of Engineering
(2005) report "Educating the Engineer of 2020" to improve the quality of
engineering education with three main objectives: understanding what
engineering is and how it is practised, developing and applying fundamental
engineering skills, and gaining practical design experience as part of a
multidisciplinary team. The book advocates the notion that engineering can be fun,
is inherently multidisciplinary, that modelling is the key for making good
engineering decisions, and that engineering is more than applied maths and science.

3. Wright's introduction to professional engineering (2002) aims to help students understand the context within which their disciplinary-centred technical skills will be used. The book provides a valuable treatment on the historical development of engineering from a European and American perspective, followed by engineering challenges for 21st century engineers in the industrialized world such as energy, maintenance of public infrastructure, reducing hazardous (nuclear) waste issues and space exploration. Later chapters provide instructive sections on engineering practice, communication, teamwork and ethics.

4. Dowling, Carew and Hadgraft (2009), like Wright, recognised the need for a text to help students develop professional engineering skills. This text provides more detailed instructional source material than Wright's text and includes major sections on problem solving approaches, sustainable development, written and interpersonal communication skills, ethics and project planning.

5. ASCE issued the “Civil Engineering Body of Knowledge for the 21st Century” (2008) to establish a “gold standard” for civil engineering education: a prescription that was intended to set a standard for educators to aspire to reach. Written by a large panel of authors of whom the majority were engineering faculty, the report provides a detailed guidance on desirable outcomes for engineering education.

In this paper, it is only feasible to discuss two issues from this study of the texts in this paper. The first aspect is the notion that the parameters of real engineering problems are seldom fully defined, and are often imprecisely known. As explained below, this is an example of how texts can create implicit assumptions through the ways that they present learning tasks for students. The second stems from the observations reported above, the connection between engineering and value. This is an example of an issue that seems to be completely missing from the texts.

**Uncertain information in engineering**

Many people characterise engineering in terms of precision and certainty. Recently a banker explained some of the difficulties of economic forecasting to my students: “All that you know about the answer that you get is that it is wrong. You just don’t know how wrong it is. It is very unlike a mathematical equation or an engineering solution when you know that the answer is right. You have to take account of that in your thinking.”

This statement embodies a common misperception about engineering, that engineering problems have known solutions for which one can “know that the answer is right.” In engineering practice, however, it is rare (and often considered a trivial case) when one can know that the answer is right.

None of the several texts examined discussed the inevitable uncertainties and gaps in the information that engineers use in their work. For example, an engineer can seldom define a precise loading (external forces acting) on a structure in advance. The in-service loading...
will depend, for example, on how the structure is used and environmental factors that cannot easily be predicted in advance. In many instances, it can be difficult to predict installation and construction loads accurately. While this is well known among practitioners, there was no reference to this reality any of the texts. As a consequence, there is no guidance for students on ways to choose an appropriate loading for design and analysis.

Instead, every sample problem presented in the texts has precisely defined parameters, reinforcing the notion that engineering is based on precisely known information, on objective certainty. Figure 1 illustrates a typical student problem that one could find in an engineering text. In this instance, students might be asked to predict the reaction forces at the two support points in response to the forces shown acting on the beam.

In order to construct a more authentic learning exercise for students, an engineering educator could replace the numbers above the force arrows with question marks. Even some of the length dimensions could be replaced with question marks. The students could be asked to estimate appropriate loads in order to design the beam instead of having the loads defined precisely, given a qualitative description explaining the intended use of the beam.

Initially students might find this kind of problem insoluble. However, the educator can suggest that students examine beams in similar applications to understand how one might estimate the loads they were designed for.

For example, students could reverse-engineer the building in which they are situated. “See that beam above you? How much weight do you think it could support without permanent deformation?” By asking the students to calculate the maximum load that an actual beam in their building can withstand, students can learn useful analysis methods and, at the same time, learn about the typical design loading needed for a specific building application. Students can then learn that existing structures can provide safe models and precedents from which they can deduce appropriate design requirements for new structures.
Connecting engineering with value

Recent work by economists has demonstrated the importance of seeking alignment in the identity and values of the organization, its employees, shareholders and even clients (Akerlof & Kranton, 2005). Major companies operating in contemporary post-industrial societies are obviously seeking economic value, but also value safety for both the community and employees, and also value respect for social, governance and environmental values.

The fact that organisations employ engineers suggests that engineers can contribute value for clients as well as wider social benefits. Yet, all five texts seem to present this as an implied assumption. None explain how the technical work performed by engineers creates value for their clients. Two of the texts (Holzapple & Reece, Wright) briefly refer back to a single quotation “Engineers can do with one dollar what any bungler can do with two dollars” quoted from Wellington (1887) without further explanation. A recent UNESCO report advocating the positive role of engineering in human development also demonstrates similar assumptions, and does not include detailed explanations on how engineering can make valuable contributions (Marjoram, Lamb, Lee, Hauke, & Garcia, 2010).

How does value arise from engineering practice, in the form of real social or economic benefits? In several studies of engineering practice, little evidence has emerged of engineers with significant hands-on participation in making the products that arise from their work or delivering utility services (Trevelyan, 2007, 2010; Trevelyan & Tilli, 2008). The value of their work, therefore, arises indirectly, through the work of other people.

For example, in deciding how to design a bridge beam, an engineer has to predict the most severe loading (external forces acting) on the beam. Standards and codes often provide guidance on how to do this, and often require a factor of safety. A factor of safety of 2, for example, means that the beam must be designed to withstand twice the most severe anticipated loading. Taking the time to predict loads more accurately, to design the beam with more ingenuity to carry a higher load, more care with material selection, procurement, manufacture, assembly, and erection may allow lower safety factors to be used. The resulting beam is lighter, consumes less material, requires less supporting structure, is easier to transport and erect on site. This is how better prediction and more care in organizing, planning and monitoring production can facilitate large cost reductions. This an example of a direct cost saving and many (but not all) engineers can explain the value of such savings.

In the research studies in different countries, few engineers seemed to be aware of indirect costs such as opportunity costs or lost production resulting from equipment failures (Hägerby & Johansson, 2002). Even fewer engineers, only two in the entire series of studies, explained a link between reducing uncertainty and added value, as explained by Browning (2000). Several interviews provided evidence that engineers were making costly decisions for their employers because they were unaware of this link.
Reducing uncertainties also can reduce financing costs. An investment with less uncertainty in financial returns can attract more conservative investors who will provide more finance at a lower interest rate and a longer payback time. This can make a big difference in the financial viability (and therefore value) of an engineering project. However, this simple connection between uncertainty and financial value seems to be elusive for practising engineers (Crossley, 2011). As a senior mining executive stated in response to some of our recent research results, “Our engineers don’t understand the business imperative of this organisation. They simply don’t get it and it frustrates me immensely.” Others refer to this issue as ‘lack of commercial awareness’.

All this analysis can demonstrate is that there is a possible connection between the absence of explanations on the economic and social raisons d’être of engineering in major texts and a significant limitation that restricts the ability of engineers to understand and explain the value of their work. Labour market economics provides a causal link between "marginal product", the financial value that an employee creates for an organization from their labour, and remuneration. Engineering work is highly autonomous: most engineers have a large influence in deciding what they do each day. It is possible that, if engineers could understand and explain the value they create, that they could improve the value created from their work as suggested by expectancy-value theory and therefore provide greater rewards for their employers and consequently gain significantly higher remuneration. Understanding non-financial values could bring similar benefits. Further work is needed to confirm this possibility.

Concluding Remarks

Analysis of the five texts has revealed, so far, about 25 significant aspects of engineering practice relevant to all engineering disciplines that are either not mentioned or presented in ways that can lead students to form inappropriate assumptions. These include aspects of teamwork and communication in engineering practice, engineering knowledge, significance of hands-on practical work, uncertainties inherent in human behaviour, engineering problem descriptions, analysis and design approaches, standards, and computational tools. All these assumptions are reinforced in one way or another, unintentionally, in ways that lead to misunderstandings about engineering practice among novices. Most of these misunderstandings are evident from recent on-going studies of novice engineers in their work environments, and some can also be seen in published literature. They also help to explain some of the observations on student conceptions of engineering found by (Dunsmore, Turns, & Yellin, 2011).

This analysis contributes a more detailed insight on gaps between engineering education and practice. The value of this analysis is that it suggests ideas for engineering educators to create more authentic practice tasks that reinforce learning of engineering concepts. This work also highlights the need for many more detailed engineering workplace observation studies to inform engineering educators: such studies are valuable capstone research projects for engineering students (e.g. Crossley, 2011). The results would almost certainly help students cross today’s divide between education and practice more easily, with the possibility that they would be significantly more productive as engineers.
Educators need to heed this advice to avoid future accusations that they deliberate mislead their students.

Acknowledgements

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Teaching practices of engineering faculty: Perceptions and actual behavior

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Abstract: In this paper, we present our study of engineering faculty teaching practices, focusing especially on faculty perceptions and their actual behavior. This is part of a larger, institutional-change-based effort to motivate changes in classroom practices at our College of Engineering to better support a diverse student body.

Introduction and Context

Ample research demonstrates that faculty teaching practices can improve student learning, engagement, and interest in engineering (e.g., Prince, 2004; Seymour & Hewitt, 1997; Smith, Sheppard, Johnson, & Johnson, 2005; Tobias, 1990), and many of these practices have been shown to be especially effective for educating a diverse student body (Prince, 2000; Seymour & Hewitt, 1997). In spite of this evidence, though, translation of research to actual teaching behavior has been slow at many institutions (Friedrich, Sellers, & Burstyn, 2009), including our own College of Engineering.

We assert that institutional change initiatives are necessary to accelerate this transition from research to practice. We further believe that these initiatives will be more effective if they are (1) grounded in research about successful faculty teaching practices, (2) integrated with local evidence regarding institutional context, student perspectives, and faculty perceptions and behavior, and (3) informed by theories of learning, faculty development, and institutional change. At University of Michigan (U-M), we have initiated research – based on these premises – to motivate faculty to change their teaching practice. Here, we report the outcomes of one phase of our research focused on understanding the current teaching practices of our faculty. Specifically, we investigated engineering faculty perceptions of their own teaching, we characterized their teaching practices through both faculty self reports and through objective classroom observations, and we explored the connections between them.

Research Questions

Our study was guided by the following research questions:

- What are engineering faculty’s perceptions of their teaching practices?
- What are engineering faculty’s actual classroom practices?
• What portion of class time includes faculty and student questions and answers?
• What portion of class time includes active learning?
• How do engineering faculty’s perceptions compare with their behavior?

The answers to these research questions are important to engineering education as they provide a baseline from which to measure change. They also are an essential first step in the design and implementation of data-driven institutional change at our College of Engineering. The data we collect will allow us to identify research-based effective teaching practices that are presently in use and target those practices that would be best to adopt in our context. Additionally, understanding ways that faculty perceptions of their teaching aligns or does not align with actual practice will allow us to better support the adoption of effective practices.

**Theoretical Framework**

There are three key components to our evidence-based approach to enabling institutional change (Figure 1). First, we will ground our work in existing research about faculty teaching practices shown to be effective in promoting student engagement and success. Second, we will situate this research in the local institutional context, building on local evidence and understanding the local reward structure and motivators for faculty change. And third, our work will be informed by theories of learning, faculty development, and institutional change. The latter component offers several useful frameworks.

![Figure 1. Our Model for Institutional Change](image-url)
Learning theory research will be important in our efforts. Social constructivism (Wertsch, 1997; Von Glaserfeld, 1989), for instance, supports our framework of using both faculty perceptions and local culture to design a plan for motivating change in faculty teaching practices. We also will employ the principles of the expectancy-value theory (Wigfield & Eccles, 2000) to understand how reward structures and other incentives play a role in faculty's motivations to change their classroom practices.

Faculty development models will guide our efforts, too. The SUCCEED model, developed by eight engineering universities in the Engineering Education Coalition, supports the value of credible engineering faculty delivering workshops on teaching and learning (Brawner, Felder, Allen, & Brent, 2002). That model has been successfully utilized to promote effective teaching in engineering. Other research shows that faculty development programs are more likely to be successful (e.g., participants will learn more and will be more likely to implement the innovation goal of the program) if the programs include a clear set of opportunities and provide sustained contact among participants and leaders (Garet, Porter, Desimone, Birman, & Yoon, 2001; Hawley & Valli, 1999; Luft, 2001).

We also will use multiple models of organizational and institutional change to guide our work. One specific model is the Strategies and Tactics for Recruiting to Improve Diversity and Excellence model, developed at U-M (Stewart, Malley, & LaVaque-Manty, 2007). The model involves a group of respected faculty, led by a content expert, who work together to understand the literature in the field and then create a series of interactive workshops to present strategies to their faculty colleagues. Effective attributes of the workshops include having data and substantive research and providing specific strategies and recommendations for action. Research about the model highlights the importance of respected faculty serving as leaders, faculty synthesizing the empirical research for themselves, and providing credible data (that is valid and can be replicated). Additionally, socialcognition models – such as those described by Morgan (1986) – which relate to the way learning new information may lead to a realization of the need to change (Morgan, 1986), will play an important role in our efforts.

Methods

Selection of Sample

We used a stratified random selection process to identify 30 courses for possible observation during the Winter 2011 term. First we excluded all courses with fewer than ten students enrolled, all graduate courses, and all non-lecture style courses. We then categorized each of the remaining 216 undergraduate, lecture-style courses as small, medium, or large (enrollments of 10-40, 41-74, and 75 or more, respectively) and as introductory or upper division (100- or 200-level and 300- or 400-level, respectively). Finally, we randomly selected 14%1 of all classes in each of five categories (1: small or medium, introductory; 2: large, introductory; 3: small, upper division; 4: medium, upper division; 5: large, upper division).

We invited the primary faculty member for each of the 30 courses to participate in our project (i.e., to allow us to observe one of her/his typical class sessions and to complete an

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optional online survey), and 26 agreed (three were teaching half-term classes that had ended by the time our project was announced, and one was not interested). Our participants varied by gender (two women and 24 men), faculty rank (six lecturers, three assistant professors, six associate professors, and 11 full professors), and instructional department. Information about the respective courses of the 26 participants is shown in Table 1. At the conclusion of the project, 25 of the 26 faculty participants received a $5 gift card for the local coffee stand (one participant declined the incentive).

**Table 1: Course information**

<table>
<thead>
<tr>
<th>Course category</th>
<th>Participant number</th>
<th>Instructional department</th>
<th>Students enrolled</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Small or medium, introductory</td>
<td>1</td>
<td>Mechanical Engineering</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Materials Science and Engineering</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Aerospace Engineering</td>
<td>43</td>
</tr>
<tr>
<td>2: Large, introductory</td>
<td>4</td>
<td>Atmospheric, Oceanic, and Space Sciences</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Atmospheric, Oceanic, and Space Sciences</td>
<td>182</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Materials Science and Engineering</td>
<td>189</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Biomedical Engineering</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Mechanical Engineering</td>
<td>92</td>
</tr>
<tr>
<td>3: Small, upper division</td>
<td>9</td>
<td>Computer Science and Engineering</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Biomedical Engineering</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Atmospheric, Oceanic, and Space Sciences</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Computer Science and Engineering</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Atmospheric, Oceanic, and Space Sciences</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Mechanical Engineering</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Undergraduate Education</td>
<td>28</td>
</tr>
<tr>
<td>4: Medium, upper division</td>
<td>16</td>
<td>Industrial and Operations Engineering</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>Electrical and Computer Engineering</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Computer Science and Engineering</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Mechanical Engineering</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>Computer Science and Engineering</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Industrial and Operations Engineering</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>Materials Science and Engineering</td>
<td>55</td>
</tr>
<tr>
<td>5: Large, upper division</td>
<td>23</td>
<td>Aerospace Engineering</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>Chemical Engineering</td>
<td>75</td>
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<td></td>
<td>25</td>
<td>Industrial and Operations Engineering</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>Industrial and Operations Engineering</td>
<td>93</td>
</tr>
</tbody>
</table>

**Faculty Perceptions of Teaching**

Each participant was invited to complete an optional, online survey. The survey included basic questions about the course s/he was teaching as well as two short research-validated inventories: Trigwell and Prosser’s revised Approaches to Teaching Inventory (Trigwell & Prosser, 2005) and Murray’s Teaching Behaviors Inventory (Murray, 1985). We requested that participants complete the survey using the specific class that we selected for observation as the context.

The revised Approaches to Teaching Inventory contains 22 items, eleven that represent a teaching approach that Trigwell and Prosser define as information transmission or teacher-focused and eleven that represent a conceptual change or student-focused teaching.
approach. A high score on either scale indicates high importance being placed on that approach to teaching; since the two scales are independent, it is possible for an instructor to score highly on both the teacher-focused and student-focused scales. Participants responded to statements about their teaching approach on the instrument’s five-point scale (1=only rarely or never, 2=sometimes, 3=about half the time, 4=frequently, 5=almost always or always).

The Teaching Behaviors Inventory includes 30 separate low-inference teaching behaviors categorized into six meta-behaviors: enthusiasm, clarity, interaction, task orientation, rapport, and organization. For example, “Gives multiple examples” is a specific low-inference behavior in the clarity category. Participants rated the degree to which they implemented each of the 30 low-inference behaviors on a five-point scale (1=almost never, 2=rarely, 3=sometimes, 4=often= 5=almost always).

Classroom Observations

Unlike other research that has studied teaching practice primarily through self-reported behavior, our research also included observational data of the 26 faculty in action. To guide the observations, we used variations of two standard protocols – the Structured Observation Protocol from University of Wisconsin-Madison (Hora, Ferrare, & Anderson, 2009) and Murray’s (1985) Teaching Behaviors Inventory. The first protocol includes items for the observer to code types of instructional method (including questions asked by faculty and by students), level of student engagement, cognitive activity of students, and material artifacts. We adapted the protocol by separating the first category into types of instructional methods and types of questions, and by adding a category for types of active learning. During the class period, the observer coded faculty behavior in five-minute segments, indicating the number and types of questions asked by faculty and students (and noting whether the former were answered) and the number and types of active learning exercises used by the faculty.

Our second observation protocol includes the same 30 teaching behaviors as the faculty survey. However, we modified the instrument for the observer to mark whether or not the faculty member exhibited each of the 30 low-inference behaviors during the class period (yes/no) and to rate the degree to which the faculty member demonstrated each of the six meta-behaviors (enthusiasm, clarity, interaction, task orientation, rapport, and organization). For the meta-behaviors, we used a simplified three-point scale because it improved consistency and inter-rater reliability in our pilot test. Two professional instructional consultants, each with backgrounds in engineering, were trained to use the observation protocols and to apply them consistently. Participants suggested a “typical” class period to observe, and one of the two consultants completed the observation.

Data Analysis and Results

For this paper, we present our results in three ways. First, we show the self-perceived degree to which each participant believes in a teacher-focused and student-focused approach to teaching (computed by summing the individual items from the Approaches to Teaching Inventory). Second, we study the five-minute segments of our classroom
observations to determine whether: (1) the faculty asked no questions, (2) the faculty asked any “non-productive” questions (i.e., questions that were not answered by the students), (3) the faculty asked any substantive questions that were answered by the students and therefore contributed to student engagement, (4) the students asked any substantive questions, and (5) the faculty used any active learning. Then for each class, we compute the percent of segments during which each of these events occurred. And third, we compare the faculty’s self-rated use of the six meta-behaviors (enthusiasm, clarity, interaction, task orientation, rapport, and organization; computed by averaging the score on the four to six associated specific behaviors on the 30-item Teaching Behavior Inventory) with the observer’s rating.

Faculty Perceptions of Teaching

As they are comprised of eleven separate items scored on a five-point scale, both the teacher-focused and student-focused scales of the Approaches to Teaching Inventory can range from 11 to 55. There are no normalized scores available in the literature because scores are considered context dependent and not absolute for a specific person. The scores, however, can be compared with our observational data to examine relationships between perceptions and actual behavior and can be used as a baseline against which we can measure changes in teaching approach. For the 25 participants who completed our survey (one faculty member chose not to do so), the teacher-focused scores ranged from 20 to 51 (average = 37.1), and the student-focused scores ranged from 20 to 53 (average = 36.4). The data are shown in Figure 2. The correlation between the two self-reported scales is negligible (0.12).

![Figure 2: Faculty's self-reported teacher-focused and student-focused approach to teaching](image_url)

Classroom Observations

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Our observational data included documentation of the ways faculty promote interaction with and among students by asking questions, by encouraging student to ask questions, and by using active learning. This is displayed in Table 2 which shows the percent of five-minute segments for each participant’s observed class period during which there was several types of activities. For example, Participant #1 asked at least one question during 81% of the five-minute segments, asked questions with no student response in 31% of the segments, and asked questions to which students responded in 81% of the five-minute segments. Similarly, students asked questions in 31% of the segments, and the faculty member used some type of active learning in 25% of the segments. Note that since a single five-minute segment could include multiple activities (e.g., one unanswered faculty question, two faculty questions answered by students, one student question, and a think-pair-share active learning exercise), the columns do not necessarily sum to 100%.

Table 2 illustrates that there is high variation in classroom style among participants. In one class (#22), the faculty member asked no questions, while in another class (#20), 94% of the five-minute segments included at least one faculty question. The table also shows that some faculty asked a lot of questions but did not succeed in getting students engaged. For example, in one class (#17), the faculty asked questions in 66% of the five-minute segments but got no student responses to questions in one quarter of the segments. Further, students asked questions in only 8% of the segments, and the faculty used no active learning in the observed class period. On the other hand, some faculty members with a high percentage of segments in which they asked non-productive questions also had a high percentage with questions to which students did respond (e.g., # 8). This could indicate the faculty rephrased questions or introduced new questions to facilitate student responses.

Noticeably, we observed very little active learning in our sample. Although a few faculty used multiple active learning exercises (e.g., #1 used four think-pair-share activities during the observed class period), and some included a single active learning exercise requiring significant time, such as a group discussion, 16 of the 26 observed class periods used no active learning.
Table 2. Amount of student engagement

<table>
<thead>
<tr>
<th>Participant Number</th>
<th>Faculty question</th>
<th>Unanswered faculty question</th>
<th>Faculty question (and response)</th>
<th>Student question</th>
<th>Active learning exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>81%</td>
<td>31%</td>
<td>81%</td>
<td>31%</td>
<td>25%</td>
</tr>
<tr>
<td>2</td>
<td>69%</td>
<td>38%</td>
<td>63%</td>
<td>31%</td>
<td>25%</td>
</tr>
<tr>
<td>3</td>
<td>92%</td>
<td>54%</td>
<td>77%</td>
<td>38%</td>
<td>0%</td>
</tr>
<tr>
<td>4</td>
<td>93%</td>
<td>27%</td>
<td>80%</td>
<td>13%</td>
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<tr>
<td>6</td>
<td>60%</td>
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<tr>
<td>7</td>
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</tr>
<tr>
<td>8</td>
<td>90%</td>
<td>80%</td>
<td>70%</td>
<td>20%</td>
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</tr>
<tr>
<td>9</td>
<td>75%</td>
<td>75%</td>
<td>6%</td>
<td>44%</td>
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</tr>
<tr>
<td>10</td>
<td>50%</td>
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<td>17%</td>
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<td>11</td>
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<td>19%</td>
<td>44%</td>
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<td>14</td>
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<td>16</td>
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<tr>
<td>17</td>
<td>67%</td>
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<td>18</td>
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<td>38%</td>
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<td>44%</td>
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<td>94%</td>
<td>56%</td>
<td>85%</td>
<td>50%</td>
<td>13%</td>
</tr>
<tr>
<td>21</td>
<td>79%</td>
<td>36%</td>
<td>64%</td>
<td>21%</td>
<td>43%</td>
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<td>22</td>
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<tr>
<td>Average</td>
<td>64%</td>
<td>40%</td>
<td>48%</td>
<td>26%</td>
<td>9%</td>
</tr>
</tbody>
</table>

Comparisons

The six plots of Figure 2 present a comparison of faculty perceptions of their teaching (from the Teaching Behaviors Inventory) and the actual practices we observed (from the observation protocol). The correlations were low in all six comparisons, ranging from 0.02 to 0.14, indicating that participants do not perceive their own actions in ways that are consistent with objective observations. For many of the six meta-behaviors, faculty reported implementing them at least “sometimes,” but our observers’ ratings ranged along the complete 3-point scale. One potential reason for this high self-perception is that faculty may be poor judges of their own practice, especially since they have little opportunity to see other teaching approaches. For example, a faculty member may believe he is fostering considerable interaction or is bringing clarity by stressing important points; but a trained observer – and possibly a student in the class – might not share this belief.
Future Research

This project is part of a larger effort which will result in an improved learning environment for all engineering students at U-M and better support for a diverse student body. Besides the work presented here, our efforts include:

- synthesizing existing literature about faculty teaching practices that support a diverse student body and situating that literature in the U-M context using data from multiple sources (student demographic and academic data from the registrar and interviews with academic advisors);
- administering a student survey and conducting focus groups with students at all levels of academic achievement to identify teaching practices perceived by students to support and to hinder their success in engineering;
- surveying all engineering faculty at U-M and conducting one-on-one interviews with some to ascertain faculty beliefs about their own teaching practices and about how their practices affect student learning and to identify factors that influence faculty motivation to change their teaching practices; and
- developing an evidence-based institutional plan for motivating change in faculty teaching practices.

Although our work is local in context, the evidence-based approach to enabling institutional change will serve as a model for others and will contribute to the larger body
of literature on how to support faculty in implementing best teaching practices in engineering education.

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Assessment of transferable competences in computing

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Abstract: The European Credit Transfer and Accumulation System (ECTS) is the credit system for higher education used in the European Higher Education Area (EHEA), which involves all the countries engaged in the Bologna Process. This paper describes a study which is part of the project of the Bologna Experts Team-Spain and was carried out with the following aims: 1) designing some procedures for the assessment of transferable competences; and 2) testing some basic psychometric features that an assessment device with some consequences for the subjects being evaluated needs to prove. We will focus on the degrees of Computing. The sample of students (20) includes first year students from the Technical University of Madrid. In this paper, we will report some results of data analyses carried out to this moment on reliability and validity of the task designed to measure problem solving.

Introduction

The assessment of competences or learning outcomes is a key concept in the European Credit Transfer and Accumulation System (ECTS) since credits are awarded when the assessment shows the competences which were aimed to be acquired (European Communities, 2009). ECTS is the credit allocation system for higher education used in the European Higher Education Area (EHEA), which involves all the countries engaged in the Bologna Process, 47 at this point in time. Most Bologna countries have adopted ECTS by law for their higher education systems (European Communities, 2009). In Spain, a decree passed in 2007 (Ministerio de Educación y Ciencia, 2007) establishes the transferable competences which any student with a university degree must have developed; these include understanding basic and gradually more advanced texts, problem solving, looking for, selecting and using information to solve problems or making decisions and the capacity to learn independently.
This paper describes a study which was part of the project of the Bologna Experts Team-Spain (http://www.expertosbet.es) and was carried out with the main aim of gaining experience in the assessment of learning outcomes, designing some procedures for the assessment of transferable competences and testing some basic psychometric features of the proposed task. It is part of a larger study, but only partial data will be discussed here.

In order to achieve the overall goals of our study, participants from different fields of knowledge (Biology, Psychology, Computing and Economy) were invited to take part in it. These participants came from 5 different universities, so that the use of criteria and standards could be compared. In this paper, we shall focus on the degrees of Computer Engineering, Software Engineering, Computing and Mathematics & Computer Science. A sample of over 200 students from these degrees took part in the general study, but only the data of 20 students taking the task purported to measure problem solving will be reported here. We will only report some results of data analyses carried out to this moment including different forms of reliability and validity of the assessment device. This work is still under progress and only initial data will be discussed. Finally, we will discuss our experience in the use of these procedures.

**Context and background**

In the context of higher education, a competence may be understood as the combination of skills, knowledge, attitudes, values and abilities that underpin effective and/or superior performance in a professional area (European Communities, 2009). In this way, when we try to assess student performance, we are interested in assessing not only knowledge, as has been the case in traditional education, but also what the student is able to do (and how) using this knowledge. By how, we understand adhering to disciplinary methodological standards and values. Thus, competence or learning outcomes assessment includes the assessment of knowledge, but is not limited to it. It is normally assessed through complex, representative disciplinary tasks that imply knowledge and are often complemented with students’ reflections whereby students justify the decisions they have taken on a theoretical and/or disciplinary base, and take into account their consequences or the values that inform them.

The starting point for this study were the basic and general transferable competences mentioned by the Decree 1393/2007 (Ministry of Education and Science, 2007) which every higher education graduate should have developed. They were selected since they are common to all grades although every discipline is expected to further introduce its own particular colouring and nuances. For this reason, they were considered at the same time to be a good basis for independent work and for making interesting comparisons. This fact gave place to two additional questions. On the one hand, we could learn about the particularities of the assessment of learning outcomes regarding different disciplines; on the other, if the structure used for the tasks was similar, we could explore to which extent assessment criteria and standards were used in similar ways.
Research questions

As mentioned above, our aim was to design assessment procedures to assess the basic competences which all graduates must have mastered by the end of their undergraduate academic life according to the Spanish law. This should be complemented by the development of assessment criteria that would allow enough objectivity when correcting and eventually grading students’ work. We also tried to validate the tasks as appropriated for the assessment of these basic competences in different ways.

Theoretical framework

In line with the standard procedures described in the literature (e.g., Wass, Van der Vleuten, Shatzer & Jones, 2001), the design of these assessment procedures has included a number of steps: 1) a detailed analysis of the facets included in each competence; 2) designing assessment tasks covering these competences and aspects; 3) developing and discussing assessment criteria which allow reliability when grading students’ work; 4) determining the basic psychometric properties that any measurement device should show, such as inter-rater agreement, internal consistency and validity (content as well as discriminant validity), following the Standards for educational and psychological testing (AERA, APA, NCME, 1999). In this paper, we will report, by way of example, on the work we carried out regarding one on these general competencies, namely problem solving. This is part of a larger study and although the original study included other aims, no other analyses will be reported here.

Method

Participants

In the larger study, one degree was selected from each of the five branches of knowledge (Arts and Humanities, Social Sciences, Engineering, Health Sciences and Sciences), although no participants from the branch of Art and Humanities volunteered to take part in the study. We also tried to have at least two higher education institutions for each degree in order to make significant comparisons. The Technical University of Madrid participates with two centres and four different degrees in Computer Sciences: Software Engineering, Computer Engineering, Computing and Mathematics & Computer Science. In order to adhere to limitations imposed for this paper, only the data secured in the two former degrees will be reported here. Table I describes the sample participating in this study.

<table>
<thead>
<tr>
<th>Degree</th>
<th>Men</th>
<th>Women</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE</td>
<td>12</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>CE</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

SE: Software Engineering; CE: Computer Engineering

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Participants were between 17 and 24 years of age (mean = 18.5). During the selection period, a total of 14 students had chosen their degree as their first option and 6 as their third. At high school, 19 students studied Science and Technology and 1 studied Humanities. Regarding the country of origin, 18 of the students were Spanish (13 of them came from Madrid) and 2 were Ecuadorian.

**Procedure**

Students participated on a voluntary basis and their work was recognised by 1 ECTS, taking into account they not only took this task but also all the general as well as the specific tasks for each competence.

**Measurements and instruments**

This section includes, by way of example, the description of one of the competences we have worked with, namely problem solving, our analysis of the facets it implies, the task designed to measure it and of the assessment criteria developed with to aims; on the one hand, making grading more objective and, on the other, breaking down the task so specific feedback can be given to students when the task is used for competence development.

**Competence description**

An approximate translation of the competence states that students are expected to able to apply knowledge to their career or vocation in a professional way and show the competences acquired which are normally showed when developing and presenting arguments or when solving problems related to their field of study.

**Analysis of the facets**

Our analysis of this competence is as follows:

1. **Presentation and argumentation of a point of view or opinion**
   a) Understanding two or more implied sides or opinions on a given issue
   b) Identifying conflict points
   c) Identifying the information needed to support an argument
   d) Organizing the information required to elaborate an argument
   e) Presenting the information by using the adequate format

2. **Problem solving**
   a) Identifying problems
   b) Developing solution strategies
   c) Determining the information required
   d) Application of knowledge to solve the problem
   e) Evaluating the solution

Since the students undertaking this task are first year students of any computing degree, a content related to a subject taught in the first semester of the degrees has been chosen. This subject was Programming.
Task designed

The task (CB2) created to measure this competence is show below.

"During a football championship, the number of goals scored by a certain footballer in the different matches was counted in order to carry out statistical monitoring of his performance. The number of goals per match, which was either a positive or null whole number, was presented in a computer system. This consisted of a programme with a repetitive structure which recognized the number of goals and showed the amount of them scored by this footballer. Some examples of the way to input the information and the results obtained are given below:

<table>
<thead>
<tr>
<th>Input:</th>
<th>Output:</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 5 0 4 0 -1</td>
<td>Number of goals: 12</td>
</tr>
<tr>
<td>0 -1</td>
<td>Number of goals: 0</td>
</tr>
<tr>
<td>-1</td>
<td>Number of goals: 0</td>
</tr>
</tbody>
</table>

The value -1 means the end of the data input, it is not a data itself and it must always appear in the input".

The following tasks regarding the text above mentioned were performed so as to meet as many aspects as possible:

1. Determine which loop (counter, sentinel) would you use. Explain and justify your choice.
2. Which condition ends the loop?
3. How should the variable associated to this condition be started and ended?
4. Which is the repeating process?
5. How should this process be started and updated?
6. The input of information has been modified and it identifies now the number of goals scored in each match, taking into account that a total of 5 matches have been played. For example:

   Input: 3 5 0 4 0  Number of goals: 12

   Question a. Now, what kind of loop would you choose (counter, sentinel...) and why?
   Question b. Why have you not choose the alternative loop?

Assessment criteria

Regarding the assessment criteria, we decided that questions 1, 6a and 6b should be graded using the values (0, 2, 4): 0 for inadequate answers, 4 for excellent answers and 2 for intermediate, whereas the values (0, 1, 2), with the same meanings stated above, should be used in the rest. Questions 1, 6a and 6b have a stronger weight since they involve a deeper knowledge of the subject which is being assessed. Knowledge in control structures is required for this task but in a natural language taking into account the
students’ entrance level knowledge. The test was carried out during the third week of October, when students were supposed to have acquired the required knowledge.

Data analysis and results

Data regarding content validity will be presented in a separate report. Briefly, the task was sent to 2 independent experts asking them several questions such as: 1. which one of the basic competences prescribed by the ministry would you think this task measures? 2. Together with a listing of our facets analysis, which of the following facets do you think this competence includes? Please tell us which ones you think are not included in this task or which facets you think are lacking in our analysis. 3. The same as above for assessment criteria.

The results showed the agreement for question 1 was almost perfect and when it was not, we could easily accept the expert’s suggestions so they enriched our task analysis. For questions 2 & 3 agreement was above 75 % and, again, many of their comments could be used to improve our analysis. So we may conclude the expert’s judgments validate our tasks.

Two research interns were chosen in order to grade computing specific tasks in the University School of Computer Science. They were previously trained to understand and use the grading criteria. With this end, they discussed the criteria with the professors responsible for the tasks. However, given the size of the sample (20 students) we decided that both interns should make corrections together following the assessment criteria previously established; if their evaluation did not coincide, they were asked to discuss their arguments in order to find the conflict points and reach an agreement.

Tables II to IV describe some of the analyses carried out to gather information on some basic psychometric properties of the tasks. Table II shows a descriptive analysis of the data as well as an estimation of its difficulty level. As can be seen, the mean values obtained are quite high while the standard deviation is higher for questions 1 and 6b. The difficulty of the items (p-value) is medium for items 3, 4 & 5 and low for the rest. It must be born in mind that these results have been obtained with a small sample of students who volunteered.

Table 2: Descriptive values for the task

<table>
<thead>
<tr>
<th>Questions</th>
<th>Minimum value</th>
<th>Maximum value</th>
<th>Mean</th>
<th>S.D.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>4</td>
<td>3.10</td>
<td>1.51</td>
<td>0.77</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1.80</td>
<td>0.61</td>
<td>0.90</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1.35</td>
<td>0.81</td>
<td>0.67</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>2</td>
<td>1.40</td>
<td>0.75</td>
<td>0.70</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>2</td>
<td>1.30</td>
<td>0.73</td>
<td>0.65</td>
</tr>
<tr>
<td>6a</td>
<td>2</td>
<td>4</td>
<td>3.70</td>
<td>0.73</td>
<td>0.92</td>
</tr>
<tr>
<td>6b</td>
<td>0</td>
<td>4</td>
<td>2.90</td>
<td>1.51</td>
<td>0.72</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>20</td>
<td>15.55</td>
<td>3.05</td>
<td></td>
</tr>
</tbody>
</table>

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As for the internal consistency of the task, Table III shows the corrected internal consistency index as well as Cronbach’s alpha. As can be gathered from these results, some of the tasks suggested do not behave in an adequate way to measure the competence concerned. However, this gives us a valuable information on the items that should be removed (items 5 and 6b) to increase reliability.

Table 3: CICI y ALFA de Cronbach

<table>
<thead>
<tr>
<th>Questions</th>
<th>CICI</th>
<th>Cronbach’ α</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.187</td>
<td>0.327</td>
</tr>
<tr>
<td>2</td>
<td>0.533</td>
<td>0.142</td>
</tr>
<tr>
<td>3</td>
<td>0.220</td>
<td>0.304</td>
</tr>
<tr>
<td>4</td>
<td>0.494</td>
<td>0.116</td>
</tr>
<tr>
<td>5</td>
<td>-0.079</td>
<td>0.473</td>
</tr>
<tr>
<td>6a</td>
<td>0.102</td>
<td>0.370</td>
</tr>
<tr>
<td>6b</td>
<td>-0.133</td>
<td>0.506</td>
</tr>
</tbody>
</table>

Finally, Table IV shows the correlations of the overall score in this task with 3 different criteria. Of course these criteria should be considered very approximate, since they do not intend to measure competences. Instead, they represent 2 traditional gradings of the students. However, we did not have an independent measure of competences and expected at least some correlation with these measures. We also added an overall teacher’s judgment on student’s competence which was carried out by their current teachers by the end of the term.
Table 4: Intraclass correlations of the items with various grades (university entrance, mean grade in current term and Teachers’ overall judgment)

<table>
<thead>
<tr>
<th>Questions</th>
<th>University entrance</th>
<th>Mean grade for current term</th>
<th>Teachers judgments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total CB1</td>
<td>-0.288</td>
<td>-0.007</td>
<td>0.425</td>
</tr>
<tr>
<td>Total CB2</td>
<td>0.197</td>
<td>0.035</td>
<td>0.052</td>
</tr>
<tr>
<td>Total CB3</td>
<td>-0.186</td>
<td>0.158</td>
<td>0.471</td>
</tr>
<tr>
<td>Total CB4</td>
<td>0.182</td>
<td>0.471</td>
<td>0.128</td>
</tr>
<tr>
<td>Total CB5</td>
<td>0.227</td>
<td>0.606**</td>
<td>0.673**</td>
</tr>
</tbody>
</table>

As can be seen, results show a significant correlation only for total task score and mean grade and teacher judgment at current term. This could be expected since the total score is a stronger measure than any individual item it contains. On the other hand, the size of the correlation is medium, as expected.

Discussion

We must say all teachers involved were satisfied with the experience. We have a task consisting of a meaningful activity for these students which apparently taps one of the basic competences they should develop. However, some comments seem in order. In the first place, some teachers opposed to working with this task in the context of their classrooms because they understood this was an intolerable a loss of time. Taking into account competence based education needs to introduce competence assessment for development, as well as certification, this seems to show some teachers’ mentality has not undergone the needed changes to adapt to the educational reform we are experiencing yet. Of course we understand these tasks should be included in the regular work of students in the different subject matters they have. Otherwise, this is an add on that completely lacks meaning and students should not be expected to be motivated to work on these tasks.

Following the thread of this experience, there is a problem which has been raised at Spanish universities: the evolution from the assessment of contents to the assessment of competences, which is sometimes misinterpreted, as it is thought that competences must be assessed on the one hand and contents on the other, separately. Carrying out these tasks has revealed that this is not the case and assessments should not be separated. Learning outcomes should be assessed simultaneously with the contents. This is the answer to usual questions among professors, such as the following: how should I assess competences? When assessing competences, how do I know if students have learn what they “should” have learned? The answer is, of course, that the tasks used to measure competences should imply knowledge.
For instance, only two of the tasks (CB2, CB4) designed for Computer Science could be applied to some subjects included in the curriculum (Programming). Even so, carrying out these tasks required an agreement among the professors who teach the subject concerned and the agreement of their department, as a considerable amount of time is required in order to carry out these tasks. It is worth highlighting this issue, which poses a logistical problem whose solution is generally difficult to find, since the assessment of transferable competences has not been seriously considered in these subjects.

References


Acknowledgements

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Session 3: Wednesday afternoon

Topic: Learning strategies 2 – Chair: Cynthia J. Atman

A Variation Theory Approach to Develop Learning Progressions for Engineering Concepts

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Abstract: Learning progressions are a useful tool for describing the development of student understanding and for informing instructional practice. In this paper, we describe how we have applied Variation Theory to develop a learning progression for “size and scale” that is grounded in empirical data on student’s conceptual understanding. We argue that this approach not only offers a systematic way of describing levels of understanding from students’ exhibited conceptions, but also generates learning progressions with unique features that may offer advantages over traditional learning progressions.

Context

Learning progressions provide “descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as students learn about and investigate a topic over a broad span of time” (Duschl, Schweingruber, & Shouse, 2007, p.214). They can generate specific guidelines for structuring curricula, guiding instruction, and assessing learning (Catley, Lehrer, & Reiser, 2005; Duschl et al., 2007; Smith, Wiser,
Anderson, & Krajcik, 2006). The increase of their popularity is evidenced by the growing number of studies that have explored the progression of students' understanding of concepts from biology (Roseman, Caldwell, Gogos, & Kurth, 2006), chemistry (Liu & Lesniak, 2006; Stevens et al, 2007) physics (Alonzo & Steedle, 2008), and environmental science (Anderson, 2007). Developing learning progressions for engineering concepts would undoubtedly be useful, but we have yet to see studies in this area

Most learning progressions are concerned with the acquisition of content knowledge or the ability to exhibit certain performances (e.g. Roseman et al., 2006). They are constructed through an “expert-defined” approach, in which experts in the field define a series of levels denoting what students should know or should be able to do at different stages of learning. We contend that such “level descriptions” are not sufficient or even accurate, because they may rely too heavily on students' ability to memorize facts or the nature of the assessment tasks used, and do not account for the subtle stages between novice and expert understanding. In contrast, several studies (e.g. Anderson, 2007; Stevens et al., 2007) have employed an inductive approach to developing learning progressions. These studies undoubtedly yield valuable findings, but we are concerned about the lack of a theoretical framework in the analysis of empirical data. Without such a framework, the resulting learning progressions are vulnerable to over-interpretation by the researchers and/or the contexts in which student understanding or performance were assessed.

Research Questions

This paper seeks to accomplish two goals. First, we would like to advocate the use of theoretically guided, empirically-based learning progressions as a methodological approach to characterize student understanding of critical engineering concepts. As an illustration, we will demonstrate how our phenomenographic research on student conceptions of “size and scale” (previously reported at REES) led to the development of a learning progression for undergraduates. Second, we will discuss the advantages of applying Variation Theory (Marton & Booth, 1997) as theoretical framework for constructing learning progressions. We will argue that learning progressions resulting from this approach not only systematically describe levels of understanding, but also go beyond the common approach of “level descriptions” by revealing the critical elements that distinguish the levels.

Similar to Delgado and colleagues’ (submitted) work, our main focus for “size and scale” is on how students conceive of objects of dramatically different sizes (i.e., very small to very big), and how they apply numerical scales to represent their size differences. This concept is of great importance in the emerging field of nanoscience (Stevens, Sutherland, Schank, & Krajcik, 2007) because it is fundamental to students’ understanding of size-dependent properties that are unique at the nanoscale. Much difficulty regarding this concept, however, has been reported (e.g. Tretter et al., 2006; Drane et al., 2009), both in terms of understanding the absolute and relative sizes of objects (particularly those at both ends of the spectrum), and generating or interpreting scale representations for these objects.
Theoretical Framework

Variation Theory

Developed from phenomenography, Variation Theory (Marton & Booth, 1997; Marton & Tsui, 2004; Marton & Pang, 2006; Pang & Marton, 2005) views conceptions in terms of awareness, and learning in terms of changes in the learner's awareness structure as it relates to a concept or a phenomenon in general. That is, different conceptions correspond to awareness at different levels of complexity that are derived from different ways of experiencing a phenomenon. The variation between conceptions is due to the different aspects of the phenomenon that the learner is aware of, or is able to discern when he or she experiences the phenomenon. The variation in learners' awareness or how learners experience a phenomenon can be described in terms of aspects or dimensions of variation -"the different ways of experiencing something are different ways of experiencing the same thing, the variation in ways of experiencing the same thing, the variation in ways of experiencing it can be describe in terms of a set of dimensions of variation" (Marton & Booth, 1997, p.108). Learning is considered to take place when students become aware of the aspects of variation that they have not been able to discern previously.

Aimed at describing and explaining variation within learners' conceptions or experiences, Variation Theory usually leads to “an outcome space” that consists of a hierarchical set of increasingly more sophisticated categories of conception or understanding. This structure, together with its empirically driven nature, makes Variation Theory an appropriate choice to guide the development of learning progressions. Most importantly, it points to a systematic way of characterizing the different conceptions that students exhibit, namely, to identify the critical aspects of variation that set their understanding apart from each other.

Methodology

To understand students’ conceptions of “size and scale”, we conducted a series of three studies. As the focus of this paper is not on the studies themselves, but the use of Variation Theory in interpreting the results, only essential details of the studies are provided here. Further information can be found elsewhere (Light et al., 2007, 2008; Swarat et al., 2011).

Participants were undergraduate students enrolled in a first-year engineering course and a non-major materials science course at a major Midwest university in the USA. Both courses included units focused on nanoscience. The first study was more exploratory in nature. It involved 12 students from diverse backgrounds in task-based, think-aloud interviews. Students were asked to order a list of objects of widely varying sizes (football field, elephant, typical science textbook, human hair, bacterium, virus, and atom) along a line, and then to apply a numerical scale to represent their size differences. The second study used a similar methodological approach, but the interview focus was narrowed. Students (n=20) were given scale examples generated in the first round of interviews, and asked to evaluate their appropriateness. The third study administered a set of assessment items in the form of multiple choice and short answer to 111 students. These items were
developed based on the findings of the previous two studies, and were aimed at revealing
the variation in students’ understanding. Results reported here are based on data collected
from all three studies, as they each help decipher part of the “outcome space”. Guided by
Variation Theory, our analysis aimed to identify the different ways students viewed the
role of the scale in representing different objects and how they explained the structure of
the scales. We also place special emphasis on characterizing students’ conceptions in such
a way that contrasts between them would reveal the aspects of variation that distinguish
them.

**Findings**

Eight categories of conception were identified, which describe a hierarchy of successively
more sophisticated understanding with category eight being the most sophisticated (See
Table 1). These conceptions also belong to four super-ordinate categories — Fragmented,
Linear, Proportional, and Logarithmic. According to Variation Theory, each category is
distinguished from the next one on one aspect of variation. The aspects of variation are
inclusive, which means that the awareness of an aspect that separates conception
categories that are further along in the progression implies the awareness of the aspects
that differentiate any of the less sophisticated categories. The progression is thus defined
by the increased complexity of students’ awareness of the aspects of variation students are
aware of, the more sophisticated their conception is.

Category one and two represent conceptions of scale that are fragmented in nature, which
describes the view that objects belonging to different “worlds” (i.e. the macro-, micro-, and
nano-world) are too different to be represented on a continuous scale; in other words,
they each need their own separate scale. What sets these two categories apart is the aspect
of variation “Integrated of numbers”, which refers to whether any numerical
measurements of object sizes are integrated with the scale of choice. The category one
conception places objects on the scale qualitatively (i.e., the sun is far away from the atom,
because it is much bigger), but does not use any numerical systems to quantify the
ordering.

Categories three and four both reflect the belief that a scale based on absolute size
differences (i.e. by using subtraction) is most appropriate for representing objects of
widely varying sizes as those given in our studies. They are qualitatively different from the
fragmented conceptions, because they demonstrate the awareness of “Continuum”, the
key understanding that a scale is a continuum that can represent both very small and
very big objects regardless of which “world” they belong to. The aspect of variation “Log
scale awareness” highlights the difference between category three and four, i.e., category
four is more advanced because it indicates the attempt to incorporate some features or
components of the logarithmic scale in scale construction.

Categories five and six represent proportion-based understanding of scale, which means
that the appropriate scale for objects differing much in size should be based on the objects’
relative size differences (i.e., by using division). The aspect of variation “Proportion”
clearly specifies this feature, as it differs from the linear conceptions that are based on

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absolute differences calculated through subtraction. The difference between category five and six lies in whether the use of a common factor (most commonly 10) is used in representing the proportional differences between the objects, as specified in the aspect of variation "Powers of 10 (P10)".

Categories seven and eight are the most sophisticated conceptions in our learning progression. They both reflect a correct understanding of the logarithmic scale. What distinguishes them from the proportional conceptions, particularly the P10 scale, is the aspect of variation "Equally space intervals" -the ability to translate the P10-based comparison into appropriate representation on a log scale (i.e. the equal spacing between adjacent powers when labelled on a log scale). The difference between category seven and eight is a subtle but important one. Though both conceptions view the logarithmic scale as the most appropriate representation for objects of dramatically different size differences, category seven still holds the belief that the log scale is an “artificial” invention suited for scientific purposes only, and does not offer a “real picture” of how objects differ. In comparison, category eight sees the log scale as equally “real” as the linear scale, and understands when and why to apply each scale.

**Table 1: Learning progression for “Size and Scale”**

<table>
<thead>
<tr>
<th>Superordinate categories</th>
<th>Fragmented Scale is viewed as a fragmented structure, unable to connect different “worlds”</th>
<th>Linear Scale is understood as having a linear structure representing direct observation or experience</th>
<th>Proportional Scale is understood as having a “semi-logarithmic” structure representing proportional differences</th>
<th>Logarithmic Scale is understood as having a logarithmic structure representing “powers of 10” based differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conception categories</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Description</td>
<td>Scale orders detached “worlds” qualitatively without numbers</td>
<td>Scale orders detached “worlds” with numbers, but each “world” requires separate scale</td>
<td>Scale follows a linear structure, without reference to any log scale components (e.g. terminology, visual representation, basis of construction)</td>
<td>Scale incorporates log scale components, but does not reflect proportion-based thinking</td>
</tr>
</tbody>
</table>

**Discussion**

As the “size and scale” example demonstrates, the application of Variation Theory to learning progressions yields not only levels of understanding, but also specific features
that differentiate the levels. These features, described by the “aspects of variation”, are useful in that they point out the specific “threshold” a learner needs to go through in order to reach the next level. Among the seven aspects of variation identified in our learning progression, we believe that “Continuum”, “Proportion” and “Equally spaced intervals” are of particular importance, because awareness of these aspects requires the acceptance of a new way of thinking about numerical differences.

The identification of the aspects of variation is of great practical value. Using the learning progression as a diagnostic tool, teachers could assess student conceptions, and then identify the key aspects of the concepts of which students have yet to gain awareness. These aspects could then be made salient in subsequent instruction to help students discern them, and thus move towards sophisticated conceptions. Success of this approach, and more generally, the potential influence of identifying aspects of variation in student conceptions on classroom instruction, have been discussed in several studies (Akerlind, 2005; Marton & Pang, 2006; Pang & Marton, 2005; Swarat et al, 2011).

Emphasis on developing awareness of aspects of variation is likely to lead to instructional practices that not only help students gain knowledge and skills, but also the ability to perceive and interpret a concept from different perspectives in order to discern all of its crucial features. This ability is perhaps more important than the specific knowledge and skills, because it is useful in a wide range of learning situations that are not bound to certain knowledge domains. In fact, the ability to become aware is consistent with what the Preparation for Future Learning theory of transfer (Bransford & Schwartz, 1999) advocates - the ultimate goal of transfer is the ability to assess and learn in a new environment. That is, as the awareness of different aspects of variation may require different ways of “experiencing” a concept or phenomenon, students are likely to learn in the process how to change their view points to discern variations, an ability that will surely prove useful in novel learning situations.

The application of Variation Theory encouraged us to explore the differences between the conceptions that students exhibited rather than student performances. As a result, our learning progression characterizes individual conceptions, not individual students. This unique feature is particularly useful when students exhibit multiple, inconsistent conceptions, a phenomenon often observed as students navigate the paths from novice to expert (Alonzo & Steedle, 2008). In our learning progression, an individual student does not have to be placed at one level of the progression. Instead, his or her multiple conceptions could be mapped simultaneously, demonstrating the inconsistency within the student’s understanding, and revealing the specific aspects of variation that he/she has not gain fully.

Building the learning progression based on conceptions also freed us from being limited to assessment tasks used to probe student understanding. Since descriptions of each level in the learning progression go beyond student performances in certain assessment situations, our learning progression is perhaps more versatile. Specifically, the learning progression can be used to guide the design of assessment items fitting the needs of different student populations or instructional purposes, as long as they probe the aspects
of variation that distinguish the conceptions. In fact, the use of different assessment items is advantageous, because they tend to elicit multiple and often inconsistent conceptions students hold, which, as discussed above, can lead to more accurate diagnosis of student understanding and thus more effective instructional interventions.

Conclusion

We have demonstrated the application of Variation Theory to the development of a learning progression for "size and scale". The learning progression resulting from this approach, with its identification of aspects of variation, not only helps us understand possible paths that students go through to achieve sophisticated understanding, but also explains the “threshold” they need to pass in order to move from one level to the next. More importantly, the aspects of variation allow for easy application of the learning progression to the development of assessment tools and instructional interventions, an advantage that typical learning progressions lack. We suggest that this approach may be useful for developing learning progressions for other foundational concepts in engineering education. Future research will focus on development of a "size and scale" concept inventory based on the learning progression described in this paper and development of a learning progression for "surface area to volume ratio".

References


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First steps in the discovery of patterns in the academic results of telecommunication engineering students in the subjects Analysis of Circuits and Mathematics

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Abstract: In this paper, the results of six years of research in engineering education, in the application of the European Higher Education Area (EHEA) to improve the performance of the students in the subject Analysis of Circuits of Telecommunication Engineering, are analysed taking into consideration the fact that there would be hidden variables that both separate students into subgroups and show the connection among several basic subjects such as Analysis of Circuits (AC) and Mathematics (Math). The discovery of these variables would help us to explain the characteristics of the students through the teaching and learning methodology, and would show that there are some characteristics that instructors do not take into account but that are of paramount importance.

Introduction

The last six years have experienced a change in the teaching and learning methodology at university, in which professor of basic subjects of Telecommunication engineering such as Analysis of Circuits (AC) have moved from a traditional way of teaching to the application of the European Higher Education Area (EHEA) in order to improve the performance of the students.

The educational experiment presented in this paper was carried out in several stages. At the beginning, treatment and control groups were formed in AC, and some partial results were achieved. In the second stage, an analysis among all the subjects of first year students was carried out. The results of these two stages have been published in journals and international conferences on engineering education [Hernandez, Palmero et al. (2009); Hernandez, Palmero et al. (2010); Hernandez, Bonache et al. (2010)].

In [Hernandez, Bonache et al. (2010)], when conducting the statistical modelling of the student marks of AC, as a result, it was obtained that the observations were classified into two groups taking into consideration their probabilities of membership to these two groups. Hence, the threshold that divided both groups was found. Consequently, given the value x of X (mark), the threshold allowed us to decide which group an element belonged to. Now, we are interested to find the qualitative characteristics that distinguished the students of the groups that were obtained when classifying.
Taking into account the previous analysis for the marks, it can be said that there were some factors or hidden variables that were affecting significantly the academic results of the students and originating heterogeneity. That is to say, there were some factors that were producing a higher variability than the rest and, as a result, these factors were segmenting the population.

Here, it is important to point out that for the case under analysis the only information available was the marks of AC, which was not enough to look for the qualitative factors that differentiated the students of the two groups. However, it was suspected that one important factor, among others, was the following: how Mathematical tools are used in AC. The academic results in Math should have an influence in the ones in AC and could be one of the reasons for segmenting the population. Hence, in order to continue improving the performance of the students in AC, it could be interesting to study whether the results in Mathematics I (MATI) have influenced the ones in Analysis of Circuits I (ACI), and if the marks in MATI represent a factor that segment the mark in ACI.

**Finite mixture of regression**

In the third stage, which is the current one, the marks and trajectories of the students that were majoring in Sound Systems (SM) and Telecommunication Systems (TM) in the subjects ACI and Math, have been collected (MATISM, ACISM, MATITM, ACITM) for six years and compared with each other. Instructors of both subjects (i.e., ACI and MATI) have worked together and new interdisciplinary materials of study have been created [Hernandez (2010)].

The study that has been carried out from the marks of the students has been the following:

First, from the dispersion diagrams shown in Fig.1 and the calculation of the correlation coefficient (0.5345 for SM and 0.4822 for TM), it is observed both that there exists a linear relation between the independent variable MATISM (variable x) and the dependent variable ACISM (variable y), and that there also exists a linear relation between the independent variable MATITM (variable x) and the dependent variable ACITM (variable y). Hence, a linear regression model could be adjusted to the data. Nevertheless, when observing Fig. 1 deeply it can be seen that the marks in ACI are not homogeneous among students with similar marks in MATI. Therefore, it could be suggested that there are several groups for which a linear regression model would represent a good approximation. That is to say, there exists a different linear relation for groups of students for the level, the slope and the variability [Justel (2001)].

For the regression models it is assumed that the regression coefficients are the same for all the observations and it is also assumed that the sample (,)iiyx is a homogeneous group. In many cases, as it could be ours, the former assumption cannot be made if there are important variables that are not included in the model; that is, there is non-observed heterogeneity.
Therefore, second, the model that is going to be specified is a finite mixture of regression models. That is, a set of K regression models [Justel (2001); Hurn et al. (2003); Frühwirth-Schnatter (2006); Bishop (2006); Leisch (2004)]

\[ y = \alpha_i + \beta_i x + \epsilon_i, \quad \epsilon_i \sim N(0, \sigma_i^2) \]

classified by their parameters:

\((\alpha_1, \beta_1, \sigma_1^2), \ldots, (\alpha_K, \beta_K, \sigma_K^2)\)

Thus, the density function of the mixture is given by

\[ f(y|x, \Psi) = \sum_{i=1}^{K} \pi_i \Phi_i(y | \alpha_i + \beta_i x, \sigma_i^2) \]

where \( \Phi_i(\cdot | \alpha_i + \beta_i x, \sigma_i^2) \) represents the density function of the normal with mean \( \alpha_i + \beta_i x \) and variance \( \sigma_i^2 \), \( \pi_i \) stands for \textit{a priori} probabilities of such components, and \( \Psi \) stands for the set of all the parameters of the model.

Third, all the pairs \((y_i, x_i)\) are observed and the following parameters are estimated:

\[ \pi_1, \ldots, \pi_K, \quad \alpha_1, \ldots, \alpha_K, \quad \beta_1, \ldots, \beta_K, \quad \sigma_1^2, \ldots, \sigma_K^2, \quad 0 < \pi_i < 1, \sum_{i=1}^{K} \pi_i = 1 \]

In order to estimate the model parameters, the first step is to estimate the number of K-components of the model. To that end, the best model, \( M_k \) will be chosen by using the Bayesian information criterion (BIC) [Hastie et al. (2001)]:

\[ BIC_i = BIC(M_i) = -2 \log L(M_i) + p(M_i) \log n, \quad i = 1, \ldots, K \]
where \( L(M_i) \) represents the likelihood function for parameters in \( M_i \), evaluated at the maximum likelihood estimators, and \( p(M_i) \) represents the number of parameters of the model \( M_i \). The model that will be chosen is the one with the smallest BIC.

Here, all the calculations are carried out by using the flexmix Package of R [R-project for statistical computing; Leisch (2004); Grün & Leisch (2007)], and the following results are shown:

<table>
<thead>
<tr>
<th>SM</th>
<th>BIC((M_1))</th>
<th>BIC((M_2))</th>
<th>BIC((M_3))</th>
<th>BIC((M_4))</th>
<th>BIC((M_5))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1310.418</td>
<td>1325.678</td>
<td>1301.255</td>
<td>1321.326</td>
<td>1341.646</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TM</th>
<th>BIC((M_1))</th>
<th>BIC((M_2))</th>
<th>BIC((M_3))</th>
<th>BIC((M_4))</th>
<th>BIC((M_5))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1042.538</td>
<td>1047.726</td>
<td>1015.493</td>
<td>1026.922</td>
<td>1033.839</td>
</tr>
</tbody>
</table>

After \( K \) is determined (\( K = 3 \)), the second step is the estimation of the parameters. To that end, the EM algorithm is used [Bishop (2006); Hastie et al. (2001)] and a test for significance of regression coefficient [Grün & Leisch (2007)] is carried out.

<table>
<thead>
<tr>
<th>SM</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comp.1</strong></td>
<td>Estimate</td>
<td>Std. Error</td>
<td>z value</td>
<td>Pr(&gt;</td>
<td>z</td>
</tr>
<tr>
<td>Intercept</td>
<td>-0.256458</td>
<td>0.215555</td>
<td>-1.1898</td>
<td>0.2341</td>
<td></td>
</tr>
<tr>
<td>MATISM</td>
<td>0.950342</td>
<td>0.049478</td>
<td>19.2074</td>
<td>&lt;2e-16</td>
<td>***</td>
</tr>
</tbody>
</table>

| **Comp.2** | Estimate | Std. Error | z value | Pr(>|z|) |           |
| Intercept  | 0.29195  | 0.233317   | 1.2513  | 0.2108 |           |
| MATISM     | 0.28525  | 0.049154   | 5.8031  | 6.50e-09 | ***      |

| **Comp.3** | Estimate | Std. Error | z value | Pr(>|z|) |           |
| Intercept  | 3.285606 | 0.369562   | 8.8905  | <2.2e-16 | ***      |
| MATISM     | 0.521961 | 0.065578   | 7.9593  | 1.73e-15 | ***      |
Usual R convention:

Signif. codes: 0 *** 0.001 ** 0.01 * 0.05 · 0.1 1

The above results, in both cases, tell us that know we should test a sub-model in which the ordinates in the origin of two components be equal to zero (for the case of SM) and the slope of the third component be equal to zero (for the case of TM). For SM and TM, the BIC of the sub-model is obtained and compared with the BIC that were previously obtained.

<table>
<thead>
<tr>
<th></th>
<th>SM</th>
<th>BIC(M₃)</th>
<th>BIC(M₃sub)</th>
<th>TM</th>
<th>BIC(M₃)</th>
<th>BIC(M₃sub)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1301.255</td>
<td>1294.452</td>
<td>1015.493</td>
<td>1010.486</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Therefore, the sub-model for SM is chosen and the estimations of the parameters are the following:

\[
\begin{align*}
\hat{x}_1 &= 0.1129778 \\
\hat{x}_2 &= 0.2232182 \\
\hat{x}_3 &= 0.6638039 \\
\hat{\alpha}_1 &= 0 \\
\hat{\alpha}_2 &= 0 \\
\hat{\alpha}_3 &= 3.1409158 \\
\hat{\beta}_1 &= 0.9006426 \\
\hat{\beta}_2 &= 0.3313395 \\
\hat{\beta}_3 &= 0.5369262 \\
\hat{\sigma}_1^2 &= 0.2994740 \\
\hat{\sigma}_2^2 &= 0.7560400 \\
\hat{\sigma}_3^2 &= 1.7293372
\end{align*}
\]

In addition, the sub-model for TM is chosen and the estimations of the parameters are the following:
The estimated a posteriori probability that the i-th observation belongs to the j-th component 1, 2, 3 is given by [Bishop (2006); Leisch (2004); Hastie et al. (2001)]

\[
\hat{P}(j \mid x, y, \hat{\Psi}) = \frac{\hat{\pi}_j \Phi_j(y \mid \hat{\alpha}_j + \hat{\beta}_j x, \hat{\sigma}_j^2)}{\sum_{i=1}^{3} \hat{\pi}_i \Phi_i(y \mid \hat{\alpha}_i + \hat{\beta}_i x, \hat{\sigma}_i^2)}
\]

The a posteriori probabilities can be used to build groups or clusters with the data assigning each observation to the component with maximum a posteriori probability. For the case under analysis, the marks are classified in three groups (clusters) shown in Fig. 2.

![Clusters that are built with the data assigning each observation to the component with maximum a posteriori probability](image1.png)

### Table 1: Classification of marks

<table>
<thead>
<tr>
<th>SM</th>
<th>SM1</th>
<th>SM2</th>
<th>SM3</th>
<th>TM</th>
<th>TM1</th>
<th>TM2</th>
<th>TM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(31)</td>
<td>(68)</td>
<td>(195)</td>
<td>(157)</td>
<td>(49)</td>
<td>(35)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- SM 1: \( y = 0.90x \)
- SM 2: \( y = 0.33x \)
- SM 3: \( y = 3.14 + 0.53x \)
- TM 1: \( y = 2.44 + 0.55x \)
- TM 2: \( y = 0.49 + 0.55x \)
- TM 3: \( y = 0.16 \)
and the percentages of the classifications of each group are the following: SM1: 66.32%, SM2: 23.12%, SM3: 10.54%, TM1: 65.14%, TM2: 22.02%, TM3: 11.36%.

**Conclusions**

To sum up, for SM and TM there exist three heterogeneous groups in the data and we would have the attachment of each student to each one of these groups, as well. Moreover, it has been observed that in TM there is a small group (cluster) of students whose marks tend to oscillate around a constant mark in AC (TM3). In addition, it has been observed that also there are two groups (clusters) consisting of most of the students (approximately 2/3 parts) in which there would be a linear relation between the marks of AC and Math in SM and TM (SM3 and TM1).

Furthermore, observing TM1 and TM2, it could be suggested that there exists a hidden variable that will allow us to explain the membership to each one of these groups, which would occur in a similar but not so clear manner when observing SM2 and SM3. For the case of SM1, it results that the students have approximately the same marks in Math and AC. Hence, it should have to be taken into consideration the fact that there would be hidden variables that separate students into subgroups. The discovery of these variables would help us to explain the characteristics of the students through the teaching and learning methodology, and would show that there are some characteristics that instructors do not take into account but that are of paramount importance.

**Future research plans**

In order to discover significant differences among engineering students, it is important to study both the information collected from the students and the questions that would be interesting to ask them, because there would be hidden factors that we want to discover. To be more specific, from the finite mixture model that has been adjusted to the data, in order to try to find the variables that explain the above-mentioned clusters, we think that there is some information about the students that have not been taken into consideration yet. For instance, it is important to know the number of times each student has taken the subjects AC and Math. Furthermore, as these subjects are first-year, first-semester subjects, it could be possible that subjects such as Physics and Mathematics taught previously to entering university are influencing the performance of the students in their first academic year at university.

In addition, as during the educational experiment it was observed that there are groups whose marks oscillate around a constant value in the subject AC, this would suggest that these groups consist of students who have centered their preparation in Math and have probably abandoned AC. This abandonment could be analyzed by means of introducing the performance of the students during the course assignments of AC and Math, as another explanatory variable in the model.

Finally, it is important to point out that this educational experiment is an ongoing work, in which the next stage would consist of trying to discover the existence of specific characteristics of each cluster. To sum up, we would try to discover a pattern in the data,
which obviously would mean an improvement in the teaching and learning process in AC and Math. To this end, besides of the marks of the students in AC and Math, for the next stage of the educational experiment it would be necessary to manage to get additional information from the students.

**References**


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The Influence of Engineering Education on Optics Education

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Abstract: Similar to engineering education, optical engineering and science is a highly interdisciplinary field relying on knowledge from several different disciplines and research traditions. Our prior work has indicated that a diffusion problem exists in optics; despite the value of the resulting products and applications developed, the field is fairly unrecognizable to the general public and even other engineers. Photonics and engineering education are modern disciplines that are developing independently from the disciplines from which they have emerged. The opportunity for engineering education to have some influence on optics education seems apparent due to their shared youth. By exploring optics education research we look for evidence of engineering education's influence and identify potential areas of influence.

Introduction

In the United States there are eleven degree granting programs in optics and photonics with degree offerings from the associate level through Ph.D. The first program opened in 1929 at the University of Rochester (Stroud 2004) followed by the University of Arizona in 1964 (Thomas 2011); several other universities have joined in the past 80 years. As a field, optics and photonics has developed from basic optics, such as designing microscopes, telescopes and other practical lens devices to modern technology for high speed communications, laser devices such as scanners in stores, and laser machining to name a few. Many consumer technologies such as Blue Ray DVD players are direct results of optics and photonics innovations, while other consumer goods like cellular phones are indirect results of the same innovations. The small number of dedicated departments has not hampered innovation in optics and photonics; through contributions from foundational and contributing disciplines of electrical engineering, physics, and the other engineering and physical science areas, many significant technological feats based in optics have been achieved.

Unfortunately, optics and photonics are not well known. Our prior research (Thomas 2011) indicated that graduates, faculty, and optics students have to explain what exactly optics and photonics is about, even to other scientists and engineers. Homophily, within the field is another challenge for optics and photonics. Many of the optics and photonics programs trade graduates, faculty, and resources, while small, emerging companies born within the optics circle. Closed conversation within the field has limited the opportunity
for those unfamiliar to learn what the field is. It also creates challenges for recruiting new students for all degree programs, even the graduate level. Both lack of notoriety and homophily contribute to the overall diffusion challenge for optics and photonics. Rogers defines diffusion as "the process in which an innovation is communicated through certain channels over time among the members of a social system" (2003). Optics and photonics, as an innovation is not well communicated within engineering and science or beyond, yet some still find their way to the field.

Within an already close-knit community of photonics scholars, there is an even smaller cohort of researchers interested in optics education, parallel with education research in engineering. Engineering education is also small as a formalized discipline, yet reaches all of the traditional engineering disciplines in some way. A strength of engineering education is that many of those who are not highly engaged in the field are aware of its existence, however adoption of the results of engineering education research is limited (Jamieson 2009). The practice-oriented subset of the field is critical to the success of the research oriented part of the field. Jesiek (2009) discusses some of the challenges and opportunities for engineering education that are similar to those of optics and photonics. For example, optics related graduate students and faculty express knowledge and acceptance of "risk" with developing a career a less familiar field. The same risk factor, and recognisability of the field is associated with engineering education (Jesiek 2009). Engineering education has had some influence in most of the traditional engineering disciplines. Our goal for this project is to evaluate the scholarly influence of engineering education on optics and photonics education.

**Methodology**

This study uses citation analysis to evaluate the influence of engineering education knowledge in optics education. Citation analysis is used to determine research performance (the published products of research), but also and in our case research integration. In citation analysis references are counted based on some factor, be it a university, department, country, discipline, or other characteristic. “Citation analyses generate relatively short-term quantifiable items, they have the appearance of short-term research impacts, and are therefore attractive candidates as short-term proxies for research impact and perhaps quality” (Wallin 2005, Kostoff 1998). In most citation analyses, there is no consideration for the purpose of the citation, either to support or refute a concept, or as an indicator of quality work; it simply means that others have taken the time to reference. Our goal was to determine the lay of subject categories in optics and photonics education publications, with emphasis on engineering education sources. Heberger (2010) identifies subject categories as bodies of knowledge, so in this case consideration was given to technical sources and engineering education sources. This method enabled us to determine the influence of engineering education on optics education publications.

This method was chosen because we only explored use, not evaluating how knowledge of engineering education is used in optics and photonics education. Two publications were selected as sources of optics education research: Proceedings of Education and Training in
Optics and Photonics (ETOP) and Proceedings of the American Society of Engineering Education (ASEE). ETOP is an international, biennial conference sponsored by the Optical Society of America and SPIE, the International Society for Optical Engineering. The conference draws a relatively small number of participants and on average 80 papers and posters. American Society of Engineering Education is an interdisciplinary engineering education conference and includes divisions focused on engineering physics, as well as electrical and computer engineering that sometimes contain optics and photonics related work. Several other divisions within the ASEE conference proceedings also include optics and photonics education related publications. Both conference websites contain the proceedings, which is where the papers for this study were collected. All ETOP publications from the 2007 and 2009 conferences are included due to the expectation that the papers are education and optics related. For ASEE proceedings the keywords listed in table 1 were used to identify relevant papers. The keywords were selected to capture publications with any content related to the field of optics and photonics. The only results that were excluded from these keyword searches were papers that only included a keyword in the author's biographies. Our method, derived from Strauss and Corbin (2008), included open coding to examine the papers for optics and photonics education content and category development within the selected papers. The search identified 170 total articles and table 2 specifies the number of collected articles from the two publication sources. Comparative analysis of the entire document was used to determine which papers to include in the six engineering education categories that emerged: (1) lab or experiments, (2) course design, (3) assessment, (4) programs or tracks in optics and photonics, (5) K-12 education and outreach, and (6) teaching practices.

Table 1: Publication Sources and Search Terms

<table>
<thead>
<tr>
<th>Publication</th>
<th>Primary keywords</th>
<th>Publication Date Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETOP Conference Proceedings</td>
<td>• All publications</td>
<td>2007, 2009</td>
</tr>
<tr>
<td>ASEE Conference Proceedings</td>
<td>• Optics • Photonics • Optical • Optoelectronics • Laser</td>
<td>2005-2011</td>
</tr>
</tbody>
</table>

Table 2: Number of Articles Captured

<table>
<thead>
<tr>
<th>Publication</th>
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</tr>
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<tbody>
<tr>
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<td>145</td>
</tr>
<tr>
<td>ASEE Conference Proceedings</td>
<td>25</td>
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</table>

In addition to the subject categories, we also examine the journals and conferences that optics education researchers cite. After completion of citation reviews of the collected papers, it was apparent that there is a limited opportunity to examine specific authors for their influence, as there was little consistency in citations.
Findings

The findings in this research uncovered some general trends in both sets of conference publications as well as conference-based findings. Publications from both sources heavily referenced technical literature including journal articles and textbooks used to support photonics concepts. Preference for citing technical literature was apparent, but there were differences in proportion and frequency based on the conference.

Figure 1 shows the categories and quantities of optics education publications in ASEE conference proceedings. Open coding of ASEE papers was necessary because use of the keywords in table 1 included several publications that were not relevant to optics and photonics, but the keywords were included in the author biographies. Due to this finding we believe there is evidence to warrant future studies of researchers who engage in engineering education research with a background in photonics yet do not publish photonics education related work. After coding, 25 papers were identified as relevant to optics and photonics education, which is considerably small for the number of articles included in the proceedings each year. ASEE proceedings heavily referenced optics and photonics technical literature; approximately 2/3 of the total citations in these papers were technical in nature. The remaining third included engineering education reports, other ASEE conference papers, and educational psychology literature. Of the 25 ASEE optics related papers, five presented no references at all. Of the 25 ASEE papers, 12 fit into the laboratory or experiments category for paper type. The authors also hailed from several different departments, but primarily electrical engineering programs that offered some optics and photonics training for their students.

<table>
<thead>
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<th>Paper Type</th>
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<tr>
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<td><strong>Total</strong></td>
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Table 3: Optics Education Publications in ASEE Proceedings by Category

Of the 145 ETOP papers and posters the distribution of type is slightly different with an additional category of teaching. ETOP proceedings had a greater number of publications related to k-12 education. Table 2 presents the categorical breakdown of ETOP publications. There were several other interesting findings related to the ETOP publications. ETOP had a more even distribution among the categories and a greater focus was present on course design than compared to ASEE papers, which focused more on labs and experiments. Also, a dramatic increase on the k-12 focus was present in ETOP conference proceedings. ETOP proceedings also heavily cited technical literature, but the
ratio was nearly one half. As an international conference many of the references came from other countries and were in various languages, but of those references in another language majority were in German. ETOP publications referenced other ETOP publications, and other small optics education meeting proceedings, yet there were frequent references to ASEE proceedings and engineering education journals that was not found in ASEE proceedings. There was also heavy use of other science education literature. ETOP publication references offered additional conferences and publications to continue this research with other data sources.

<table>
<thead>
<tr>
<th>Paper Type</th>
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</table>

Figure 2: Optics Education Publications from ETOP Conference Proceedings

Discussion

This project sought to examine the influence of engineering education on optics education in two selected conference proceedings. Our findings indicate that the influence of engineering education resources in optics education is limited; the literature is not frequently cited in these publications. There were also differences in the categories of optics education publications based on conference. As mentioned, approximately one-third of citations in optics education conference proceedings actually come from engineering education sources. There are also indicators of homophily in optics education as many of the ETOP publications cited other ETOP and small optics education related meeting proceedings. This is definitely a contrast with engineering education’s interdisciplinary efforts to gather methods and resources from various fields. One startling result was that between both sets of conference proceedings there were only four (4) total references to major engineering education journal articles.

Future Work

The citation analysis completed for this study uncovered additional sources to research optics education publications in other photonics education conference proceedings, physics education journals, and websites dedicated to optics education. As a small portion of a larger research project, this portion represents optics education research performance. Additional studies will be done with students and faculty at optics and
photonics degree granting programs to determine the scholarly practice of engineering education.

References


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Development of new teaching activities for learning Robot Mechanics

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Abstract: The adaptation of university studies to the new European Higher Education Area (EHEA) established in the Bologna Declaration is showing the necessity of design and introduce new activities in the teaching process. Within this framework, a series of teaching activities are proposed in this paper with the aim of improve the learning of the techniques used in the mechanical analysis of industrial robots and increase the students’ interest in the contents included in the subject “Robot Mechanics”. The aim is to overcome the difficulties that students find in learning the “Robot Mechanics” contents. In essence, these difficulties can be summarized in two: (i) the correct interpretation and understanding of the results of mechanical analysis of a robot manipulator (3D mechanism) and, (ii) the laborious mathematical procedures used in these mechanical analysis, enhancing the students’ understanding of the concepts and calculation methods studied on the position, kinematic and dynamic analysis of manipulators.
Introduction

The adaptation of university studies to the new European Higher Education Area (EHEA) established in the Bologna Declaration is showing the necessity of design and introduce new activities in the teaching process. The aim of these activities is to make the process of change to the new role easier for both students and university teachers. First ones must assume a more active attitude, beyond mere receptors of knowledge, and the second ones must change from transmitters of knowledge in lectures to developers (covering design, plan and coordination) of diverse teaching activities that ensure the students’ skills acquisition (Zoller et al, 2003). These changes are particularly useful in technical studies where the students face multiple and diverse difficulties due to the complex problems covered by engineering studies. Within this framework, a series of teaching activities are proposed in this paper with the aim of improve the learning of the techniques used in the mechanical analysis of industrial robots and increase the students’ interest in the contents included in the subject “Robot Mechanics”. The activities were planned considering the available equipments in the “Escuela Técnica Superior de Ingeniería Industrial” (ETSII) of the University of Salamanca (industrial robot ABB IRB140, Fig 1a, which can be controlled on-line with the flexpendent unit or off-line with a computer, and an electrical gripper SCHUNK EZ64, Fig 1b) with the objective of overcome the difficulties that the students find in learning the “Robot Mechanics” contents. In essence, according to previous studies (Cabezas and Lorenzo, 2006) these difficulties can be summarized in two: (i) on one hand, the correct interpretation and understanding of the results of mechanical analysis of a robot manipulator (3D mechanism), and (ii) on the other hand, the laborious mathematical procedures used in this mechanical analysis. Proposed activities are designed to apply in a real industrial robot the analytical solutions obtained in the mechanical analysis (including both direct and inverse position and kinematic analysis), and simulating diverse industrial processes where mechanical analysis is needed, such as object manipulation, welding, cutting and so on. The aim of this work is to overcome these difficulties, enhancing the students’ understanding of the concepts and calculation methods studied on the position, kinematic and dynamic analysis of manipulators, by combining the available technical equipments with the advantages that the design and dynamic simulation software offer nowadays for multibody systems analysis of mechanical elements such as manipulators. According to previous works (Vergara, Lorenzo and Rubio, 2007; Vergara, Rubio and Lorenzo, 2008) the application of active teaching methodologies, based on skills acquisition with a direct and active role of students will provide an improvement of the learning process.
Description of proposed activities

The diverse proposed activities were developed according to the established formats: master classes, problems classes, laboratory practices, seminars, individual/collective tutoring and a final evaluation where the students show individually the acquisition of the subject skills. Each one of the proposed activities allows an adaptation of the contents to the student academic formation and complements each other with the end of improvement the learning process, solving the common difficulties that were observed in the students during the years of academic experience of the authors. Next, a brief discussion about each activity is shown with a more detailed description of the new activities that are specially focused on the active participation of the students.

Master classes are planned as the start point of the students’ basic formation of the subject contents from the theoretical background in a unique group class. These classes are mainly focused on the essential aspects and orientations about how to go further in the unit contents. At the beginning of the course the students have the subject’s notes for the monitoring of the classes.

Problem classes are considered as a direct application of the concepts developed in the master classes and allow students to have a first contact with the mechanical analysis of the manipulators covered there. During these classes the professor solves step by step some of the problems included in the problems collection available for the students from the beginning of the course. At the end of each class, a similar problem is proposed to be solved by the students as homework. The potential doubts of the students are solved in tutoring hours. Some of the proposed problems must be solved analytically and those which require the repetitions of the mathematical work can be solved with the help of
computing applications developed by the authors. The basic use of such applications is included in seminars as is latterly stated. By this way, students can analyze more complex problems whose analytical solution would require a long, repetitive and, consequently, tedious mathematical work.

Two different types of seminars classes are considered: first one is dedicated to the resolution by the student of certain relevant exercises of the problems collection with the professor assistance. During this activity, students face directly with the problem resolution revealing the potential misunderstood concepts. From this information, the professor can establish alternative activities that enhance the understanding of such concepts. Second ones are those activities, developed during the teaching period, that provide to the students a complementary formation of the subject contents, for instance, the use of diverse software applications such as Mathcad® or dynamic simulation software (Autodesk Inventor® for the analysis of any robot, or Robostudio® for the analysis of ABB robots). The use of such software applications enhances the students´ self-learning. In addition, these activities let to introduce basic issues of robot programming in Rapid (ABB programming language), very useful for the development of the practice with the robot ABB IRB 140. These seminars are planned under a purely practical point of view with a direct and active role of the students during the seminar. For these reasons, these classes should be carried out in the computing classroom.

Laboratory practices represents the student’s first contact with an industrial robot, and allows a direct visualization and check of the obtained results from both points of view: theoretically throughout the analytic resolution of the problem (problem classes) and throughout the use of the diverse computer tools. These activities are performed in small groups of 15 students that are subdivided in 5 groups of 3 students during the practice class. Next, a description of the proposed practices is detailed:

- **Practice 1: Technical specifications of robot ABB**: The main objective of this practice is to have students become familiar with the robot ABB IRB140 throughout the development of simple activities. These activities consist in searching information in the technical specifications of the robot and, when possible, compare it with the real ABB IRB140 robot: identify the different components of the industrial robot, the manipulator axes and types of movement applying the movement (Fig. 2a) axle by axle with the flexpendant unit (on-line working). Therefore, a basic knowledge of the use of the flexpendant unit for the direct control of the robot is required. Next, they must decide if a series of positions of the extreme element of the robot are accessible or not according to the robot working space that they must find out inside the technical specifications book (Fig. 2b).
Proceedings of Research in Engineering Education Symposium 2011
Madrid, 4th - 7th October 2011

Figure 2: Information provided by the ABB manufacturer used by the students to perform the first practice and apply it to the robot ABB: (a) Manipulator axes, (b) working space, (c) ranges of movement and (d) load diagram

Then they must decide if a series of combinations of axes angles are possible to be applied or not and when possible apply it to the robot (Fig. 2c). Another task is to define the maximum load allowable at a certain distance from the extreme element applying the load diagram given by the manufacturer (Fig. 2d). Finally a commentary about relevant technical information such as repeatability is given and information about safety use of the robot. This practice is developed at the end of the first unit of the subject when the students have general knowledge of the components of the industrial robot, types of control, applications, etc.

• **Practice 2: Analysis of position applied to the robot ABB IRB:** In this practice two different position problems (direct and inverse) are covered. Each one is developed in two phases: firstly simulation and secondly the application to the robot ABB IRB140. The direct position problem consists in obtaining the final position of the robot’s extreme for a given set of axes angles. The simulation stage is done with the computer simulation (student must have the knowledge of movement simulation with Inventor® and Robostudio® so the seminars Inventor® and Robostudio® must be done previously), obtaining the three cartesian coordinates of the interest point of the terminal element. Also the simulation provides an image of the robot at that position. Then, students move the robot axis by axis until the desired axes angles are reached, and take a photo of the final configuration of the robot. Next, a student checks the position of the extreme element with a laser measurement device. These coordinates are read by other student; laser device gives the z coordinate and laser spot gives the x and y coordinates. In the practice report, students compare the two solutions, virtual with simulation software and real with the ABB robot.

The second problem, the inverse position problem, consists in obtaining the values of the set of angles which applied to each axis set the robot in a given position. According to the theory, 8 different ways of raise a certain position are mathematically possible (Fu, Gonzalez & Lee, 1988). First, the students use the computer application in Mathcad® for obtaining the 8 possible solutions of the manipulator and check if one is mechanically possible according to the technical data of the robot (studied in practice 1). Then, students simulate the movement in Inventor® to all the positions observing the possible collision between robot elements for the non accessible mechanic solutions, and keeping an image of each possible solution. Then, the students apply to the robot all the mechanical
solutions, checking the final position with the laser device. As in the previous case, the students take photos of the robot at each position and comparing real and simulation in the final report. For this practice is needed previous knowledge of the use of the Mathcad® and the Inventor® applications so this activity should be performed after the seminars 1 and 2.

Figure 3: One solution of the inverse position problem using (a) simulation with Inventor® and (b) ABB IRB140 robot

- **Practice 3: Process simulation with the robot ABB IRB:** The aim of this practice is to show students how a industrial process can be programmed and executed by the robot. Three different simple processes are considered. The first one refers to the manipulation of objects with diverse geometries from a certain point inside a box to another point in other box. The objective is to make student realize the relevance of determining not only the position but the orientation of the final element. The boxes were placed in different orientations and positions over the robot gird and the students must firstly move the robot to the point A (where the object is placed with the right position and orientation), catch the object closing the jaws gripper and then move it to the point B where the empty box is placed with the right position and orientation. Then, the students calculate with the Mathcad® application the solution of the inverse position problem, simulate the eight solutions with Inventor® and decide which one of the eight is the most appropriate according to angles ranges. Finally, students program the movement in the robot and simulate it in Robostudio®. The second process is to perform a certain trajectory point by point with the robot in a given plane. This trajectory could represent a welding beam or a cutting process. The steps are the following: students design a trajectory defined by points, then they program the coordinates in the Robostudio® software and simulate the movement. Finally, they apply it to the robot ABB, where a pencil is subjected by the jaw. When the robot describes such trajectory leave on a piece of sheet a drawing that represents the trajectory of the final element of the robot (Fig. 4).
Figure 4: Inventor® simulation of the trajectory on the plane YZ

- **Practice 4: Kinematic analysis:** The last practice consists in the analysis of the two types of simple movements: the simplest circular movement of an axle and the more complex movement along a linear trajectory with a certain velocity. The first one consists in moving a certain angle and measure the time with a chronometer and to obtain the linear and angular velocity of the extreme element. These results are compared with the one obtained from both Mathcad® and Inventor® applications. The second one is to solve the inverse kinematic problem. So, firstly, students must use the Mathcad® application to obtain the numerical solution and then apply the values of the axle velocities to the simulation in Inventor®, and finally apply it to the robot. This final practice must be carried out after the theoretical analysis of the kinematic analysis of manipulators.

**Evaluation and expected results**

Activities evaluation to guarantee the skills acquisition established are planned from the following statement: apply a system of continuous evaluation that enhance and incentive the progressive study of the student during the subject development. They include non-presential ones, such as delivery of proposed works, and presential ones, such as seminars where students solve more complex problems with the professor orientation and with the help of computer applications or lab practices. Taking into account such statement, the evaluation system is considered as follows: (i) **Practices:** To pass the subject is mandatory to perform all the practices and deliver a report of them during the semester. The weight in the final evaluation is 15%. (ii) **Proposed homeworks:** As in the case of the practice, these activities are distributed along the academic year, trying to impulse that students give a reasonable time for the study of the subject. They allow professor to know if the learning process is effective or not. The weight is 15% of the final note. (iii) **Seminars:** Only seminars where students solve problems individually are evaluated for knowing if students acquire the required skills. In addition, the results validate the autonomous learning of the students. According to the importance of this activity, its weight in the final evaluation is 20%. (iv) **Final evaluation:** It is constituted by two options that student could choose before the first third of the semester. First is a conventional writing exam where student must demonstrate the skills acquisitions (solving new problems) trough
the analysis of position and kinematic analysis of an industrial robot with a similar difficulty to the ones studied in class. Second one, the students must perform a work, where an analysis of the position, kinematic and dynamic of an industrial manipulator is included, considering the programming and execution of a manufacturing process with the ABB robot, with the help of the diverse computer applications under continuous supervision of the professor. The evaluation is performed upon the memory that they must present and on brief (10 min) exposition and defense of the work. Both options let to know the final degree of learning of the subject and, therefore, they have the higher weight (50%). The expected results of the application of the proposed activities included in this paper are: (i) improve the spatial visualization and the interpretation of theoretical results of the mechanical analysis of the manipulator, (ii) apply the knowledge acquired in the theoretical and problem classes to a real industrial robot, (iii) enhance the student learning process and promote the student self-learning through the performing the diverse proposed activities, (iv) promote the new role of the student in the process of teaching/learning within the EHEA framework, (v) enhance the skills acquisition both specific and transversal included in the subject “Robot Mechanics”, (vi) enhance the comprehension of the theoretical concepts and the analysis procedures by the visualization in situ of the real manipulator, (vii) put in direct contact students with a real robot in all the stages of an automation robots process: design, programming, simulation and execution of the process.

Conclusions

Within the new EHEA framework established in the Bologna treatment, in this paper a proposal of teaching activities applied to the subject “Robot Mechanics” was exposed. In order to overcome the traditional problems associated with the students learning. The real results of these activities will be revealed until the instauration of the fourth course of the mechanical engineering degree in the academic year 2012/2013. However, these activities were tested this year in volunteer students showing promising results, increasing student motivation, active participation, interest for the subject contents and, consequently, an improvement of the learning process. The continuous evaluation leads to the skills acquisition with an expected increment of the success rate of the subject.

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Investigating the characteristics of successful collaborative learning activities

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Abstract: Given that engineering is a practice-based profession, one of the benefits of collaborative learning is that it provides the opportunity to simulate this practice within classroom activities. While not replacing the benefits of actual practice, thoughtfully designed collaborative learning activities provide opportunities for students to construct and test their knowledge while developing their professional judgement. Hence, it is important to identify the common characteristics of collaborative activities that improve student learning. Based on the results of our research we hypothesised that with the correct scaffolding, activities that include integrated collaborative conversations improved the learning within small group activities. In this paper we report the first step in a research project to determine the characteristics of successful collaborative learning activities that include integrated peer conversations to assist academics in designing their own successful collaborative activities. To test our hypothesis we first examined a series of studies that report the effect of collaborative activity on student learning to identify any common characteristics that seemed to have a positive impact.

Context/Background

In 2000 Johnson, Johnson & Stanne published their meta-analysis of 164 studies comparing the effectiveness of eight different collaborative learning activities to individualistic and competitive learning methods. They found that "...if cooperative learning is implemented effectively, the likelihood of positive results is quite high. Results, however, are not guaranteed."((Johnson, Johnson, & Slanne, 2000)p.16). Since 2000, published studies in discipline areas as diverse as engineering, business, law and medicine, have reported on the use of collaborative learning activities in the higher education sector. While some studies claim that these activities increase student learning (Dana, 2007; Koppenhaver & Shrader, 2003; Lisk, 2003; Stark, 2006); studies by others report no significant improvement in learning when using collaborative activities compared to the traditional lecture method (Haidet, Morgan, O’Malley, Moran, & Richards, 2004; Lancaster & Strand, 2001; Lucas, Baker, & Roach, 2001).
Research Questions

Given that engineering is a practice-based profession, collaborative learning provides the opportunity to simulate this practice within classroom activities. While not replacing the benefits of actual practice, thoughtfully designed collaborative learning provides opportunities for students to construct and test their knowledge while building their professional judgement (Billett, 2006). Hence, it is important to identify the common characteristics of collaborative activities that improve student learning. We hypothesised that some of the differences reported by (Johnson, et al., 2000) were probably due to a number of factors including implicit variations that were not the focus of these published studies, for example how well the activities aligned with both the learning outcomes and assessment of the courses. Furthermore, in our research, in agreement with (Lucas, et al., 2001), we have found that embedding peer conversations in the course design enhanced the learning within collaborative activities.

Embedding conversations in the course involves academics having a more systems approach to instructional design, rather than seeing the group activities as a ‘bolt – on’ to existing practices. Our experience suggests the following sequence of activities: individual pre-discussion work, in class/meeting small group discussion, individual re-test, in class/meeting small group discussion involving more complex problems or the same concepts in a different context.

Individual pre-discussion work by the students appears to make the conversations more effective. Furthermore, our experience shows that more than one iteration of individual activity followed by peer discussion improves the learning outcomes for most participants (Willey & Gardner, 2011). This could be, for example, having students test their individual knowledge after the first discussion and then having groups collaborate on solving a problem in a slightly different context or at a higher level of complexity than the initial problem.

Aspects of the overall course context such as the assessment scheme and whether the academic explains their instruction design also affect students’ participation and benefits gained from collaborative activities. In our research we found that the formative nature of the activities allowed students to focus on learning the material rather than strategically trying to maximise their marks. An instructor explaining why the students are working in groups and how they should be approaching their group activity in terms of their own learning also seems to help students learn from their peers.

As part of the initial stages of a systematic investigation of whether these characteristics have a positive impact on student learning in collaborative activities that include peer conversations, we examined a range of studies that report both improvements in learning and no significant difference compared to non-collaborative activities.
Theoretical Framework

All the studies in this review investigated methods of collaborative learning that included conversation/discussion between students as a part of the process. From a social constructivist perspective, the inclusion of conversations between students, and between students and the instructor, is the essential component in the process, as it is through these conversations that students (& academics) renegotiate their concepts of a topic to come to a shared understanding. (Nicol & Boyle, 2003) found “Students reported that peer discussion resulted in their reconceptualising important principles as well as learning about new methods and approaches to problem-solving.”

Method

We define a collaborative learning activity to be one where there is purposeful interaction between two or more students, and we restrict our analysis to examining the quality of the learning reportedly achieved, usually by test scores or course grades, but sometimes additionally by students’ perceptions. The reported studies claim a range of success with a collaborative learning method, but broadly speaking, we identified eight that concluded that compared to the traditional lecture method, collaborative learning led to significantly ‘better’ learning (positive studies) and five which did not. The five that did not still found that learning occurred, but that this learning was not significantly better than that achieved using lectures. We denoted these studies as being neutral.

Our investigation was limited to published studies that focus on collaborative learning activities in courses in the higher education sector where students and instructors interact face-to-face (>50% of the time in class). This synthesis includes quantitative, qualitative or mixed methods research and evaluation studies that have been published in English in refereed journals or conference proceedings since 2000. Studies with no theoretical framework or which were judged to have a poor evaluation method were not included. In comparing the reported outcomes in these papers, we considered the following factors:

- Whether there was individual work to be completed before student discussion occurred (pre-work),
- Where the student discussion occurred (e.g., in class or out of class),
- Whether the reported activity was summative or formative, and
- Whether the instructors explained the reasons for using the collaborative learning method to the students involved in the study.

Findings

All studies investigated student learning in the higher education sector, except for Haidet et al. (2004) who looked at medical residents. While there are several characteristics that can be compared across these studies, a summary of the main aspects pertinent to our interest are listed in Table 1 to assist comparison.

The size of the groups in these studies ranged from 3 to 7 with most instructors targeting 4 as the ideal group size. In the educational literature, these would be classed as small
groups. Nicol & Boyle (2003) compare two published collaborative learning methods (peer instruction vs. class-wide discussion). Although group size was not the only difference between these two methods it was a significant variable and students felt that the small group discussion was more effective than the class-wide discussion method.

**Individual pre-discussion work required**

In the study reported in this paper most of the collaborative learning processes with significant positive benefits required students to answer some relevant questions individually before the group discussion occurred. However, three of the eight did not report whether individual pre-discussion work was required or not. Amongst the neutral studies three of the five required individual pre-discussion work, one did not and one did not report whether it was required or not. So while most studies seem to suggest individual pre-discussion work is useful, it is not the only factor contributing to the success of the activity since some neutral studies included it too.

The other significant variable between the two peer learning methods reported by Nicol & Boyle (2003), apart from the group size as discussed above, is that with the peer instruction method students were required to answer the problems individually before engaging in discussion with their group members about which was the correct answer and why. They found that: “Almost all the students interviewed expressed a preference for starting the concept test with individual thinking and an individual response, rather than with peer discussion. They were forced to think about the problem, and to formulate their own reason for their selected answer before the group discussion. Having constructed their own answer students felt they benefited more from the subsequent peer discussion.”

Haller et al (2000) suggest a reason why getting students to individually attempt questions before the discussion can help the group function. They analysed the conversation of four groups as they solved group homework problems and identified two types of conversation sequences: transfer of knowledge sequence (teacher/pupil relationship) and the collaborative sequence (shared thinking out loud to achieve joint understanding). Furthermore they found that interaction patterns referred to as ‘constant pupil’ and the ‘blocker’ tended to interfere with group function. In the constant pupil interaction the same group member needs to have concepts explained by other members of the group which can lead to these members feeling slowed down or that the constant pupil is not pulling their weight. From this research these authors recommend that students should attempt the homework problems alone before the group meeting as this would minimise the constant pupil type of interaction.

**Formative or summative activity**

Ramsden (1992) tells us that students experience our courses through the assessment tasks and allocate their time depending on what activities will earn them marks. Academics have often interpreted this as meaning they have to allocate marks to an activity to get students to do it and that the marks allocated reflect the value of the learning we expect students to get out of that activity.
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<td>Both in &amp; out of class</td>
<td>Summative</td>
<td>Not reported</td>
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<td>Lisk (2003)</td>
<td>team mark vs stages of team development</td>
<td>Not reported</td>
<td>Yes</td>
<td>summative</td>
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<td>Stark (2006)</td>
<td>Benefits of team exams</td>
<td>Not reported</td>
<td>Yes</td>
<td>Summative</td>
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<td>Haberyan (2007)</td>
<td>lecture vs TBL format</td>
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<td>Yes</td>
<td>Summative</td>
<td>Not reported</td>
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<tr>
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<td>Collaborative vs lecture format</td>
<td>Yes</td>
<td>Yes</td>
<td>formative</td>
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<td>Haller et al. (2000)</td>
<td>Dialogue of 4 student teams analysed</td>
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<td>Both in &amp; out of class</td>
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<td>Ellis, et al. (2008)</td>
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<td>Yes</td>
<td>summative</td>
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<td>Yes</td>
<td>Summative</td>
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<td>Lucas et al (2001)</td>
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<td>Yes</td>
<td>Summative then formative</td>
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<td>Kittleson &amp; Southerland (2004)</td>
<td>engineering Discourse to describe how students worked in a group</td>
<td>No</td>
<td>In labs &amp; out of class</td>
<td>Summative</td>
<td>Not reported</td>
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Table 1: Selected characteristics of published studies of collaborative learning activities
Of the eight studies that reported significant learning in collaborative activities, two (Nicol & Boyle, 2003; Willey & Gardner, 2011) used formative group learning activities and one (Dana, 2007) used a combination of both summative and formative activities. The reasons that most activities in the study used summative assessment are unclear. There was no way of distinguishing if summative was chosen as a matter of course as it is what's typically done, or because the instructors believed that activities needed to be summative for students to engage with them. After our success with formative activities, we suggest that the collaborative learning activities themselves do not necessarily have to be summative, however engagement will be reduced if the learning resulting from the formative activities does not significantly and efficiently help students prepare for their eventual summative assessment.

Learning method explained to students

Of the eight positive studies, three (Dana, 2007; Nicol & Boyle, 2003; Willey & Gardner, 2011) report that students were given an explanation and justification of the use of the collaborative learning method used by the instructor. Amongst the neutral studies only Lancaster and Strand (2001) explain how and why team learning was being used to their treatment group who were using team-based learning.

In the neutral study by Ellis et al (2008) however, they conclude that “... it is clear that many students do not necessarily see how to approach discussions... in ways that promote understanding. Setting discussion tasks without helping students see the potential benefits are... unlikely to lead to good learning outcomes.”(p.280) This suggests that participant performance in collaborative activities improved with understanding of both the learning method and objectives. We suggest that such explanations provide a metacognitive framework to help participants obtain the full benefit from a collaborative learning activity.

Future research plans

This analysis, although constrained to fit in the page limit for the conference, is the first step in designing a research study to investigate the requirements for improved learning outcomes in collaborative activities with integrated peer conversations. In particular, we will investigate:

- How individual pre-work completed before class/meeting makes a significant difference to the effectiveness of the subsequent conversations for learning,
- How making the collaborative activity summative or formative changes the behaviour and/or engagement of the participants and whether this has an effect on their learning,
- Whether explaining the reasons for & the theory behind the group learning method makes a significant difference to how well participants perform in subsequent individual assessment activities testing higher order thinking skills, and if so determine some of the contributing factors, and
The effect of including an individual activity after the discussion to allow students to reassess their learning gaps.

An evaluative framework that is proposed for this future research is the Learning Variables framework used by Lucas et al. (2001). One of the most significant variations they found between a collaborative activity and a traditional lecture method relates to the variable labelled 'rehearsal'. Rehearsal relates to the process of reviewing information. They distinguish between two types of rehearsal, maintenance rehearsal which is simply repeating information in rote fashion, and elaborative rehearsal which integrates new information with old information. Peer learning activities create opportunities for focussed discussion which supports "...elaborative rehearsal, a process important for developing meaning and transferring information from short to long-term memory" (p.74). This appears to be a useful concept for modelling the conversations that take place in collaborative learning activities and for indicating impacts of the characteristics of interest listed above.

Conclusions

Examination of thirteen selected studies suggests that learning outcomes in small groups can be improved if participants are required to answer some relevant questions individually before the group discussion occurs, and if the learning method is explained to participants before they start. While most studies used summative assessment of collaborative activities, this was not a requirement for success and the purposeful integrated design of a whole course is likely to be more important than whether a particular activity is summative or formative.

References


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Task and networking balance as key to satisfaction with team performance

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Abstract: As today’s market place becomes globally more competitive, industries expect engineering teams to perform innovatively within cost and time constraints. The team depends on effective collaboration to balance technical knowledge for innovation with dynamics for implementing a project. This paper summarizes an engineering approach for analyzing attitude and satisfaction surveys (in & out) and team building observations (internal forces). Students initiate a project with high expectations that the team will balance completing tasks and maintaining good relationships. A team centered and supportive environment emerges from using the task and networking roles that promised some level of satisfaction with the outcome. A balance of task and networking translates into satisfaction with leadership and management, which correlates to satisfaction with performance. The team’s ability to get work done with respect to its vision for the project governs its satisfaction with performance.

Introduction

As the market place becomes globally more competitive, the engineering industry expects teams to perform effectively and efficiently. Shared contributions create a supportive environment to formulate and to solve the design issues effectively defining an innovation. The environment places greater expectations that the team performs efficiently within time and budget constraints. The industry, therefore, needs people who can balance task and networking functions.

Context

Widman (1997) defines success as the perception of satisfaction 1) on the part of the participants and 2) with the processes that achieve it. Hanna and Wilson (1991) indicate that team satisfaction comes from perceptions concerning leadership because it is about motivating people (Verma and Widman, 2002) and concerning management because it is about managing people (Reh, 2010). Leadership engages members to get work done (Verma and Widman, 2002); whereas management establishes processes to get work done within time and budget (Widman, 1997).

Leadership plays a key role during the creative phase in which the team formulates a vision addressing the needs of stakeholders. Management plays a key role during the critical phase when the team resolves design issues addressing the needs. Leadership and management are essential systems to successfully implementing a complex, open-ended project and each is tied to the project life cycle.
The combination supports the team as it weeds out the less desirable options in order to allocate time and resources toward those options with the best chances of success. An effective technical assessment evolves from a leadership system that engages people and information in the formulation and solution of design issues (Rudd and Watson, 1968; Douglas, 1988). Implementation relies on a management system that enables the team to operate effectively (Pahl and Beitz, 1996; Ullman, 1997).

Benne and Sheats (1948) promote successful team performance based on a balance of networking and task functions. Although scholars differ about phases (Tuckman, 1965) that teams go through during decision-making processes, they agree that these two functional responsibilities are critical for successful team performance (Bales, 1950; Bales & Strodtbeck, 1951; Bennis & Shepard, 1956; Pfeiffer and Jones, 1979). Networking functions target the leadership system required to effectively engage others in innovation. Task functions address the management system required to efficiently get work done. As observed by Applbaum (1992), Jones and Bearley (1994) and Jones (1999); the balance leads to successful problem solving. Knecht and Gale (2005) report that student teams require the entire semester (life of the project) to achieve this balance.

The balance creates a team centered environment recognizing the contributions of all members. MacPhail, Roloff, and Edmondson (2009) propose that effective collaboration emerges when team members understand, value, and integrate contributions of other team members with their own. Lovelace, Shapiro, and Weingart (2001) observe that collaborative communications encourages the freedom to express concerns about innovation. According to Clark (2001), the lead offers constructive feedback concerning team’s performance. Reh (2010) observes that a manager creates an environment to communicate problems in order to get work done within time and budget constraints. A team centered environment makes it possible for each team member to become an active contributor.

**Research Questions**

The engineering design course creates a learning environment focused on mentoring a balance between task (management) and networking (leadership) functions. The balance ultimately leads to satisfaction with the performance of the team. The focus on engineering design too frequently emphasizes the technical skills of the team. The imbalance favors the status quo over innovation and can ultimately result in delays and costly overruns. For first-year engineering students, exposure to the balance establishes a realistic attitude toward authentic engineering design.

Balance plays a key role with respect to effectively and efficiently implementing an open-ended problem-solving experience.

**Premise**

P1. Balance between preparing a quality product and maintaining good relationship emerges from a supportive environment.
P2. Balance between preparing a quality product and maintaining good relationship evolves as the project progresses.

P3. Satisfaction with effective leadership and efficient management lead to satisfaction with performance.

Framework

Confronted with the challenge of designing an excavator to collect and store regolith during a return mission to the lunar surface, Team CRATER began by solving the problem before formulating a common goal for the project. The team focused its attention on an outcome, sidestepping the task functions leading to an innovative solution and the networking function necessary for engaging the unique contributions of its members. The project plan presentation was a discouraging experience for the team culminating with the conclusion that its rover did not meet the needs of the client.

Although the client rejected the proposed solution, he also provided the catalyst for the team to regroup and develop a common goal focusing its attention on a fresh perspective. The team changed its operational strategy to capture advantages of its shared contributions. Each member brought a unique or distinctive perspective to the project. The shared contributions created a supportive environment enhancing the performance of the team. The team won the local exhibition to represent the university at the NASA Heads-Up Competition. Its multidimensional presentation captured its shared contributions and played the key role in the team’s success in marketing its unique design — first place honors.

Students learn about the decision making process through an engineering design model that introduces an engineering culture. A sequence of project-centered courses illustrates a stage-gate strategy for project evaluation advocated by Ulrich (1984). The model synthesizes technical assessment, management, leadership, and document systems as the increasing demand for accuracy and detail coincide with an increasing technical literacy. The model, illustrated schematically in Figure 1, addresses needs of future graduates identified by organizations such as the American Chemical Society, American Institute of Chemical Engineers and ABET:

- Technical Literacy
- Creative Problems Solving
- Team Work Skills
- Communication Skills
Following an initial attempt to solve the problem, Team CRATER recognized the need to create a shared identity. It constructed a network to effectively employ leadership and document systems to innovate a quality product. It developed a supportive environment to efficiently integrate technical assessment and management systems necessary to produce a quality product.

The design intent (purpose) for this study is to examine and refine management and leadership systems defined for the engineering design process. The rationale is 1) to initiate an empirical model characterizing the intent and 2) to refine the curriculum based on findings from the modelling effort. Outcomes entail 1) a description of the balance between focusing on a quality product and maintaining good relationships, 2) illustrations of the maturation of the team in terms of the balance, and 3) a basis for tools to support first-year engineering design teams.

Methodology

This paper summarizes a portion of data collected from three instruments used to assess team work and performance in a first-year project-centered course. The method, described by Knecht (1998), explores expectations and attitudes through the surveys defining the balance between task and networking functions. Survey questions from Jovanovich and King (1998) and Kaplan (1989) were modified to assess expectations coming into and attitudes and satisfaction following completion of the design project. The study also examines the progression of task and networking functions that occur as the team moves through Tuckman’s four phases. Teams conduct a teamwork exercises at the various phases of the project; half of the teams perform and the other half observe performing teams using an observation sheet refined from the work of Eberhardt (1987).

The analysis focuses on team success in terms of satisfaction with performance creating baseline routines between satisfaction and management and leadership. The study defines an empirical model relating functions and roles critical to the implementation of an open-ended problem.
Participants (study sample) consisted of first-year engineering students representing approximately 8.3 percent of the class. Over the study period, 141 students representing 31 teams were surveyed. The Registrar enrolled these students creating a random sample. The population contained 25.5 percent women representing the average female enrollment. The same faculty member mentored teams, eliminating a mentoring variable from the study. The study cohort, therefore, represented first-year engineering students enrolled in the design program.

Findings

Engineering students come into the design experience with concerns about team oriented projects. They expect that they will assume responsibility for the technical assessment. The expectation stems from experiences in high school in which they provided the primary technical role to team exercises. Students also take on the project with high expectations to work with students like themselves. These past experiences lead the students to expect a balance in which all members of the team complete tasks while maintaining good team interaction. The correlation, depicted in Figure 2 (expectations) and described in the following equation, characterizes a tight but scattered relationship ($r^2 = 0.29$) between balance and two functional variables queried in the expectation survey.

$$Balance = 0.35 \left( \frac{Support}{Each \ Other} \right) + 0.15 \left( \frac{Focus}{on \ Quality} \right) + 2.19$$

As they come into higher education, engineering students take on the challenge of a project with high expectations about participating in a highly motivated and supportive team.

Attitudes following completion of the project evolve to a more sensible awareness about functions that governing team dynamics. The team recognizes that balance evolves from the team’s ability to support each other. The correlation illustrated in Figure 3 (attitude) and described in the following equation portrays a more significant relationship ($r^2 = 0.63$) as the team progresses through the project.

$$Balance = 0.64 \left( \frac{Support}{Each \ Other} \right) + 0.05 \left( \frac{Open}{Communication} \right) + 0.02 \left( \frac{Focus}{on \ Quality} \right) + 1.14$$
The team building exercises complement implementation of the project and enable visualization of the balance between task and networking functions. The distribution of functions, illustrated in Figure 3, demonstrates a progression toward balance as the project evolves. During the forming phase, students observe that the team initially focuses on task (75:25 split) to produce a quality product. Moving from the forming to the norming phase, the team develops a network that engages members and supports team decisions (67:33 split) while maintaining a high regard for the task functions. As the team moves into the performing phase, increasing application of networking functions (55:45 split) balance task functions necessary to produce a quality product.

The attitude survey and team building exercises informs the team about the importance of supporting the shared contributions of all team members (premise 1). Developing an effective networking component balances the task component for successful open-ended problem solving. This team building process evolves throughout the various phases of the project (premise 2).

Satisfaction with performance relies on the team’s ability to define a compelling vision that resolves needs of the stakeholders. Leaders not only define vision but also engage members with direction – a strategy for action. Clark (2001) comments that the team expects the leader to use perspective to engage the members – to provide networking
within the team. The correlation based on leadership, depicted in Figure 4 (leadership model), describes a significant relationship \( R^2=0.87 \) between satisfaction with performance and leadership (ability to design and solve, direction, and interactions), defined by the following equation:

\[
\frac{\text{Satisfaction}}{\text{with Performance}} \left( \frac{\text{Leadership}}{\text{Model}} \right) = 0.28 \left( \frac{\text{Define \& \ Solve}}{} \right) + 0.32 \left( \frac{\text{Team \ Interactions}}{} \right) + 0.26 \left( \frac{\text{Direction}}{} \right) + 0.62
\]

Verma and Widman (2002) observe that leadership plays an important role with respect to satisfaction with performance because it concerns engaging people to take action. The leader creates a supportive environment to inspire commitment and engage those willing to act on their contributions. A team contract documents the commitment and sets the standards for this environment.

Satisfaction with team performance relies on the manager’s ability to get work done. Management addresses the task functions (organization and structure) required to implement the strategy addressing the needs of the stakeholders. Reh (2010) observes that managing the team improves satisfaction with process. The correlation based on management, illustrated in Figure 4 (management model), describes a strong relationship \( R^2=0.82 \) between satisfaction with performance and management (ability to plan and organize, meet goal, and how work gets done), defined by the following equation:

\[
\frac{\text{Satisfaction}}{\text{with Performance}} \left( \frac{\text{Management}}{\text{Model}} \right) = 0.25 \left( \frac{\text{Plan \& \ Organize}}{} \right) + 0.33 \left( \frac{\text{How work \ gets \ done}}{} \right) + 0.40 \left( \frac{\text{Meets \ Goals}}{} \right) + 0.17
\]

The manager is expected to create a supportive environment to communicate problems that hinder efficient team performance. Satisfaction with performance relies on the team’s ability to produce a realistic schedule for getting work done in terms of the project goals.

Team CRATER advanced a team contract to satisfy the needs of the stakeholders resulting in a successful marketing campaign. It also created a detailed schedule to utilize its shared contributions completing the excavator design under greater time constraints. A balance
of effective leadership and efficient management led to satisfaction with its performance implementing the project (premise 3).

**Conclusions**

The team must put into action its technical knowledge to develop innovative products and its dynamics to implement projects. High expectations that team members support each other sets the stage for a project-centered learning environment focused on producing a quality product. These expectations mature as team members observe the importance of open communications. Satisfaction with team performance emerges from a balance of task and networking functions. The balance translates into satisfaction with leadership and management, which correlates directly to satisfaction with performance. Team satisfaction with its performance, therefore, relies on its ability to get work done with respect to its vision for the project.

**Recommendations**

The study develops a case for the following actions:

1. For the course: balance task functions focused on a quality product and networking functions focused on team relationships.
2. For the team: prepare a team contract to set standards for engaging others in the project.
3. For the team: create a project schedule to structure the organization for getting work done.
4. For future research: combine surveys and exercises to refine the understanding of how teams implement the design process.

**References**


Tuckman, B.W., (1965), *Developmental sequence in small groups*, Psychological Bulletin, 64, 384-399


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Towards technology stewardship: tools for encouraging student engagement

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Abstract: Getting more specialist engineering faculty members involved in the practice of high quality engineering education research (EER) has been a recurring concern at conferences and has been addressed in various initiatives over the last decade. We consider the technology stewardship concept proposed by Etienne Wenger et al. to be a fruitful area for engineering educators who have been increasingly faced with decisions relating to IT-based tools arising from a rapid proliferation of IT technology and tools and a growing emphasis on quality assurance in higher education. Choices need to be made in areas of technology selection, design and adaptation and as these decisions require competences from both engineering and pedagogical domains, the engineering instructor needs to be able to draw upon both these areas of knowledge and in this paper, as part of a pedagogical framework, we set out to illustrate the processes of tool design, adoption and adaptation in the service of teaching and learning from a technology stewardship perspective.

Introduction

Since the reorganisation of Portuguese higher education brought about by the introduction of the Bologna Process in the academic year 2006-07 (DGES) the authors have been working with a variety of technological instruments to enhance learner engagement and promote active learning. In the process a pedagogical framework has been developed and we have found Wenger’s technology stewardship concept (Wenger, White and Smith, 2009) to provide a useful perspective on technology in the service of teaching and learning. Believing that this approach can be useful to other EER practitioners, we present here some examples from our own work as a proof of concept of its relevance in guiding technology decisions.

Research questions

To assist the work of engineering faculty who work with technology to encourage student engagement, the authors set out to see if Wenger’s technology stewardship approach, one
originally developed in the field of learning communities, can be usefully applied in the field of EER. The question could thus be formulated: how could the concept of technology stewardship play a useful role to guide technology choice decisions in EER?

**Technology Stewardship**

With the increasing emphasis on Quality Assurance in European higher education (Quality Assurance and Accountability) and a rapid proliferation of IT technology and tools which make claims to help achieve this, engineering educators here have been increasingly faced with decisions relating to tool design and selection – issues described by Wenger, White and Smith (2009) as falling within the domain of technology stewardship. Trayner (2007) originally described technology stewards as “those who know both the local context and needs, who know the technology market, and know how to weave together the two” and this definition has been expanded by Wenger, White and Smith (2009) in their recent book Digital Habitats as follows: “Technology stewards are people with enough experience of the workings of a community to understand its technology needs, and enough experience with technology to take leadership in addressing those needs. Stewardship typically includes selecting and configuring technology, as well as supporting its use in the practice of the community”. Many engineering educators may recognize this as describing a growing portion of their professional activity although in the engineering education domain we would also want to include tool design as part of the remit of technology stewards. Since the publication of Digital Habitats in 2009 (Wenger, White and Smith, 2009) the concept of technology stewardship has begun to be applied in a variety of learning communities but we are unaware of work to date in the field of engineering education. Various authors have referred to the dangers of making technology selection decisions which are not grounded on sound pedagogical foundations (Bates and Poole, 2003 and Laurillard, 2009) and the framework we have employed is based on the perspectives espoused by Bates and Poole and by Laurillard. A strength of Wenger’s approach is that he places learning at the centre of the process and an analysis of learning needs as the first step from which subsequent decisions about technology will flow.

In the engineering education context we would characterize technology stewardship as a process in the service of teaching and learning that involves the design, adoption or adaptation of educational technology and the subsequent facilitation of its use and in this paper the authors aim to share our experience with examples of each of these three processes.

**Methodology**

We adopted an exploratory qualitative methodology as being the most appropriate for this study. Although our approach in this paper is predominantly qualitative in that we aim to show in a global way how the technology stewardship concept can be useful in the EER context, as a proof of concept, we do illustrate with quantitative data obtained from the use of the technology described while we give examples from our own work of how we have approached the adoption, design and adaptation of tools to encourage active learning and student engagement in undergraduate engineering courses.
Technology stewardship in Practice - proof of concept

Three main examples are presented. In the first we consider the selection of online self and peer assessment applications where we consider three options: SPARKPLUS, WebPA and an open source LMS.

Secondly, we describe our experience with the design and development of the Learner Activity Monitoring Matrix (LAMM) used to monitor student activity in the lecture classroom and give examples of how the data obtained from this approach can be used by faculty members and departments aiming to make the traditional lecture class more effective as a learning environment. In a previous conference paper we have compared the LAMM with the VOS and audience response system (clicker) approaches to this type of measurement and characterize our experience in the design research process (Carvalho and Williams, 2009).

Thirdly, we present an example of how an online LMS can be adapted to facilitate student peer voting, describing how this was incorporated into a civil engineering subject over three semesters and present data obtained.

We close with conclusions regarding the usefulness of the technology stewardship concept in EER and indicate planned future research areas.

Student Self and Peer Assessment – technology adoption

The use of collaborative groups in a curriculum unit is a common practice adopted by instructors because of the important competences acquired from the related activities. However, the contribution of each student within a group cannot always be assessed. Beside the more traditional activities involving curriculum content, each the student was expected to assess their own and their peers’ performance. SPARKPLUS, an online tool designed to facilitate the use of self and peer assessment developed by the University of Technology Sydney and hosted on their server, was employed for this within the context of collaborative group-work outside and inside the classroom.

A three-stage procedure was applied:

- Stage 1: Group preparation of whole-class presentation – a group of four to five students prepare a short presentation on a topic proposed by the instructor;
- Stage 2: Theme Presentation – the group presents the topic in the classroom;
- Stage 3: Self and Peer Assessment – using the SPARKPLUS application students assess their own contribution and performance and that of their peers in the group.

The development of competences involving judgement skills and peer evaluation is promoted and with these activities students are encouraged to reflect on their own and their peers’ contribution to teamwork and at the end SPARKPLUS calculates two factors: SPA which is a measure of the contribution of each member to the work of the team and SAPA the ratio of a student’s own rating of themselves compared to the average rating of
their contribution by their peers. These two factors are available for consultation by individual students and the instructor.

![Figure 1: Contribution within the group and individual response according to the criteria](image)

An advantage of this application is that it outputs data in various formats including individual student and group radar diagrams and in Excel format thus facilitating statistical analysis. For example, a study by Beamish, Kizil, Willey and Gardner (2009) at Queensland University suggests that academically stronger students tend to underestimate their own contribution (rate themselves lower than they are rated by their peers) and vice versa.

The application aims to reduce the probability of collusion between group members in evaluating each other by providing rating via a slider rather than simple numerical or Lickert scale and it also facilitates the identification of students aiming to beat the system and allows the instructor to exclude them from the marking process.

**Student Self and Peer Assessment – technology adaptation**

Another tool with some common purposes, i.e. student peer and self-assessment, was implemented. Although the ideal tool for this part of the process would be a dedicated online application like WebPA or SPARKPLUS, which we have previously used, it was decided to explore the possibility of adapting a commonly installed LMS to achieve the same purpose. This can be achieved by adapting the quiz function found in Moodle 1.0.

A six-stage procedure was applied:

- Stage 1: Student sign-up – this is an optional activity which if completed contributes to the final subject mark;
- Stage 2: Ice breaker task to get familiar with the online interface;
- Stage 3: Group preparation of a report – a group of four to five students prepare a short report on topics proposed by the instructor;
- Stage 4: Peer revision – a revision of the report is done by a different student group;
- Stage 5: Group preparation of the final version of the report – students prepare the final version of the report after the suggestions made by their peers;
- Stage 6: Self and Peer Assessment – using the online self and peer assessment application students assess their own contribution and performance and that of their peers in the group.

The LMS self and peer assessment application does allow the instructor to export data into Excel but overall the procedure requires a greater time investment than would a dedicated applications like WebPA or SPARKPLUS (Neto, Williams and Carvalho, 2010).

**Learner Activity Monitoring Matrix - technology design**

Several in-class activities from two online activity banks (Felder and Brent and Paulson and Faust) were adapted. From these lists a few activities were selected to be used in a variety of course contents, namely: In-Class Teams; Think-Pair-Share; Minute paper; Regular uses of students' names; The "One Minute Paper"; Muddiest (or Clearest) Point; Affective Response; Clarification Pauses; Wait Time; Discussion; show of hands voting; active review sessions, and student revision lists. The implementation of in-class active learning techniques can be monitored using a Learner Activity Monitoring Matrix (LAMM) which we have designed for the purpose. This is a simple semiquantitative tool that uses in-classroom observation or post-class video observation to monitor the degree of student activity during the implementation of AL techniques in their classes. It also allows an individual instructor or team to focus on the question of learner activity during class contact time and develop efficient techniques to increase it. More detailed information on the use of the LAMM and its use to generate an Activity Index and Participation Parameter for each observed lesson can be found in previous publications (Carvalho and Williams, 2009 and Neto, Williams and Carvalho, 2009).

Table 1 show an example of evolution the Activity Index (AI) and Participation Parameter (PP) values collected for 22 observed lessons of an individual lecturer who was introducing active learning techniques into her lecture classes (an AI value of 30 corresponds to a lecture where learners are essentially passive listeners throughout the class).

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Table 1: LAMM results for an individual instructor

Overall, the instructor's perception of increased learner activity and engagement over the period under study is clearly reflected in the semi-quantitative data obtained from the
LAMM-registered observations (Neto, Williams and Carvalho, 2009). The use of AL techniques seems to have a favourable contribution to the attendance as shown in previous work (Neto, Williams and Carvalho, 2009). Although these initial results represent a relatively small population, it is interesting to see that they reflect findings from other studies involving Active Learning and Audience Response Systems (clickers) which reported improvements in attendance when student activity in lectures was recorded by clicker responses (although only in cases where this activity contributed to more than 5% of the final grade) (Caldwell, 2007).

Analysing the data obtained from the use of the LAMM in 107 observed lecture classes, Table 2 shows a comparison between the % time engaged in lecturing (i.e. students passively listening) for both AL-oriented and traditional lecturers in our study.

<table>
<thead>
<tr>
<th>Lecturers</th>
<th>% lecture time</th>
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<tr>
<td>AL oriented (n = 92)</td>
<td>62</td>
</tr>
<tr>
<td>Traditional (n = 15)</td>
<td>93</td>
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Table 2: LAMM results comparing Al oriented and traditional lecturers

Peer voting procedure using an online LMS – technology adaptation

It was felt that there was a need for additional practice in resolving quantitative technical calculations in a range of contexts as in exams of previous years it was noted that students often had difficulty when confronted with applications of learned procedures in less familiar contexts. Accordingly an Online Learning Management System was used to provide learners with additional practice in critical analysis and allow them more flexible time management.

The survey function commonly found in LMS such as Moodle or Blackboard allows one to increase learner engagement with the material under study by introducing a peer voting process. This is essentially an online application of what Paulson and Faust refer to as Active Review Sessions – “In the traditional class review session the students ask questions and the instructor answers them. Students spend their time copying down answers rather than thinking about the material. In an active review session the instructor poses questions and the students work on them in groups. Then students are asked to show their solutions to the whole group and discuss any differences among solutions proposed”. The online asynchronous implementation has the additional advantage that it allows more time for learner reflection than conventional review.

A three-stage procedure was applied:

- Stage 1: Individual problem solving - students were given a statement online and had a week to post a justified comment to that statement. Once students post their answer they can see those of others. The solutions remain online but cannot be altered;
• Stage 2: Peer Selection – Individual critical analysis - students are allowed a week to vote for the best solution posted;
• Stage 3: Completion – the lecturer comments on the winning solution and gives a model answer. A symbolic prize may be awarded to the most successful contribution.

The benefit of this procedure is that it increases student engagement by encouraging them to compare their own solutions to the questions posed by the lecturer with those of their peers. The students’ participation level for stage 1 of a first question achieved a value near of 90% of the maximum number of students attending to class. This aspect reveals an important participation level although a decrease is observed along the semester (as well as class attendance) which is strongly dependent on external factors like tests and assessed assignment deadlines for other curriculum units (Neto, Williams and Carvalho, 2009).

![Graph showing contribution within the group and individual response according to the criteria](image)

**Figure 1: Contribution within the group and individual response according to the criteria**

From the last three years, where these measures started to be applied, allied with AL techniques in classroom, the average attendance registered during the last five weeks of the semester came from 1.2 to 1.4 times higher than the corresponding values obtained in 2007/08. With respect to the success rate, when comparing the academic years from 2007/08 until 2010/11, an increment of 15.5%, 13.7% and 14.0%, respectively, was observed. Thus, from the data collected it is possible to verify a favourable effect on both student engagement and success rates.

**Conclusions**

In the work presented here we have mainly aimed to illustrate how we have found this particular conceptual approach to be useful in guiding our own practice. In the contexts presented, the type of framing recommended by proponents of the technology stewardship approach has proved valuable in approaching decisions concerning technology in the service of teaching and learning and we believe it can provide a useful framework for EER practitioners to approach technology decisions in that it stresses the
prior definition of learning needs and aims to cultivate a learning community approach among faculty.

Furthermore, we believe an approach based around the design, adoption or adaptation of technology provides a perspective that can prove attractive to engineering specialists not hitherto involved with EER who are likely to be familiar with such decisions in other contexts. However, we are still at the stage of defining the data we should be looking to gather and what might be appropriate strategies to gather it in order to validate the approach.

**Broader questions relating to this work that are still in need of clarification**

1) Is there a place for this kind of work within EER: should it be categorized as “application” or “advances” rather than “research”, for example?
2) How best to design research to study the usefulness of the technology steward approach in engineering education;
3) How to gather this kind of research data on an appropriate scale within the contexts that many aspiring EER practitioners find themselves worldwide i.e. with little access to significant research funding or to the collaboration of doctoral students in the field.

**References**


**Acknowledgements**

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Design-based research as a methodology for investigating learning in the engineering education

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Abstract: Design-based research has been found to be a particularly useful methodology for investigating complex systems, by enabling manageable parts to be examined, and by providing both theoretical insights and practicable interventions. This paper describes the author’s experience of applying design-based research to an investigation of one element of team-based learning, namely “co-creating learning intent”. It presents a model for the application of the methodology that helps to focus research by defining key decision points in an iterative process, and arrives at theoretical insights that can be applied in much wider contexts. It is important to note that this is a work in progress and represents only the first steps in the process: further refinement, including input from other researchers into team-based learning, is anticipated before the full research implications of the methodology and its implementation can be presented.

Introduction

The author has been involved in researching and teaching team-based, project-based and problem-based tertiary courses for over fifteen years, with a particular interest in pedagogical approaches to engaging students in their own learning. Developing a sense of “ownership” in their learning process is an important factor in achieving successful learning outcomes (Zimmerman, 1994) and underpins the current trends towards the greater adoption of reflective practice in engineering education (Prpic, 2005; Stansberry and Kymes, 2007; Yancey, 2009).

However, implicit in the idea of wanting to engage students with what (and how) they are learning are the questions (amongst others) of what content should the class cover, what methods should be used in exploring that content, what outcomes are required and how will successful achievement of those outcomes be assessed? Answers to these questions can become clearer if students can articulate the intention of their involvement with the class, guided by the teacher’s understanding of the outcomes to be achieved, in a process called “co-creating learning intent” (CCLI) (Prpic, in preparation).

Despite its clear potential for leading to deeper and more effective (and life-long) learning, CCLI is by no means self-evident, particularly in terms of what is entailed and how it is implemented, and the author has embarked on a program of research into this aspect of team-based pedagogy. Given the variety of potential variables involved and the need to
develop a theoretical framework for CCI as described below, design-based research ("DBR") has been adopted as the most promising research methodology to apply.

The purpose of this paper is to present the author’s inquiry and experience with exploring CCLI in a specific engineering classroom context. This paper describes the DBR methodology that has been adopted and the findings and insights that have arisen from the process thus far. It is important to note that this is a work in progress and represents only the first steps in an iterative process: further refinement, including input from other researchers and other disciplines, is anticipated.

**Context**

The author teaches a third year project-based subject entitled Leading in a Complex World. This subject was initially developed as one of the University of Melbourne’s "breadth" subjects, which form part of the new Melbourne Model introduced in 2009 (The University of Melbourne, 2010).

By their nature, breadth subjects are multidisciplinary and open to enrolment by students from any faculty, not just engineering. Breadth subjects are intended to provide students with broader perspectives that will equip them with graduate attributes necessary for responding to a world of ever-increasing complexity.

**Leading in a Complex World** was presented over a 12 week semester as a weekly 4 hour workshop session in which students worked in small teams to explore a complex system. The overall educational paradigm used was **project-based learning**. Content, in the form of either catalytic questions or expositions of theory about such topics as leadership, complexity, teamwork and self-directed learning, was provided progressively throughout each session, followed by activities designed to facilitate active engagement. Active face-to-face participation in class was mandatory.

The initial design of **Leading in a Complex World** drew on the author’s experience in project-based learning. The subject was intended to provide students with an opportunity to explore complex real-world systems and to develop proposals for initiatives they might take to bring about changes they have identified. This year, the complex system chosen for investigation was Megacities. Students self-selected into groups based on specific "Topics of Engagement" (ToE), such as transport, population growth, micro-communities, and environmental impacts. Student assessment comprised participation (20%), reflective writing (20%), stakeholder analysis (20%), analysis of ToE from different disciplinary perspectives (20%) – all of these were submissions by individual students – and a final project report prepared collaboratively by each team (20%).

**Research questions**

The author was particularly interested two fundamental questions: “What does Co-Creating Learning Intent really mean?” and “How do I design classroom interventions that will achieve Co-created learning intent?”
In engaging with any system that presents a number of research possibilities, it is necessary to make decisions as to which possibility should be pursued and by what method, and how the focus of the research can be narrowed (Joseph, 2004).

An initial investigation of the literature showed that there was no specific theory about Co-creating learning intent, nor were there any explicit prescriptive methodologies that might apply. In beginning to unpack these initial questions it was apparent that a research process that accommodated the complexity of the author’s situation – a new degree model within the university that promoted breadth and multidisciplinarity, a new subject, and a new approach to teaching – was required. Thus even in grounding the concept of CCLI in the specific context of the author’s subject, there were a number of emergent variables needing to be researched.

From the literature, it appeared that DBR would provide a suitable research methodology (see below). Applying DBR in the current context has proven to be a journey in itself, which began with the questions “How can I apply DBR methodology in this context?”, “How can DBR as a methodology be developed within engineering education? and “What theoretical insights can be gleaned from the author’s process that could inform future investigations?”

**Theoretical Framework – Design-based research**

Design-based research (DBR) (Edelson, 2002; Bell, 2004; Middleton et al, 2008; Wang and Hannafin, 2005) is a pragmatic research approach to the design and enactment of teaching interventions, grounded in theory and committed to delivering outcomes that are constructed in real-world contexts.

In contrast to laboratory experimental research, DBR is applicable where multiple variables are involved, where the control of those variables is difficult or unlikely and where quantitation is difficult or even illusory. Nevertheless, the aim of DBR is to provide a body of evidence in support of theory. Despite its similarity to many engineering design processes, DBR has not as yet been widely used in engineering education research.

DBR possesses four fundamental attributes that are important for the task in hand – it is interactive, iterative, flexible and builds theory. Thus it benefits from multidisciplinarity and from the collaboration of not only researchers but the students themselves. Indeed, students become participants and contribute to the decision-making process (in contrast to laboratory-based investigations, where it is generally only the researchers who make decisions). Clearly, too, the process benefits from, and requires collaboration of practitioners, with differing skills and perspectives.

The iterative nature of DBR, where the research progresses from analysis to design to evaluation and thence to redesign, is another fundamental attribute. Expressed another way (Edelson, 2002), DBR builds on prior research to develop clear research goals to produce empirical results. Systematic and detailed documentation of the process and results then allows retrospective and formative evaluation, leading to generalisation that can be applied both to refining the research and to other contexts.
This iteration also provides an inherent flexibility in the DBR process: for example, researchers are able to respond to the real-world variation and unpredictability in their subject (such as the decisions and directions provided by students) in the re-iteration process. This has been critical to our research into the co-creation of learning intent as described below.

One of the fundamental attributes of DBR is its commitment to delivering outcomes, as both theories and practical interventions. As summarised by Edelson, these fall into three main areas: domain theories, which relate to „learning situations involving students, teachers, learning environments and their interactions”; design frameworks, which lead to guidelines that provide a solution to a particular type or class of design challenge, and design methodologies, which are guidelines and prescriptions for implementing a set of designs. Thus DBR ultimately aims to provide generalisations from the current context that support, expand or otherwise improve other contexts.

Methodology and Findings

Design-based research theory informs the practice of DBR directly. Because it is an iterative, practice-based, embodied and lived methodology, in which, to draw on quantum physics, the observer becomes the observed, the findings inform subsequent iterations and therefore need to be discussed concurrently. In the author’s case, the methodology used is summarised in Figure 1.

![Figure 1: The author's design-based research process](image)

Figure 1 shows a number of important features. The first thing to note is that there are three main components or phases, with the individual researcher (the author) playing a role in each:
1. the research team phase, which established the background of the project, developed the „strategic framework” collaboratively and, at the time this paper was written, had arrived at the point of „piloting” the framework;

2. the teacher / individual researcher phase, in which the interventions aimed at achieving the desired outcomes are designed and documented; and

3. the teacher engaging students phase, in which the interventions are „trialed”, their effectiveness evaluated, further refinements or modifications proposed, and new insights into the theoretical underpinnings of the intervention gained.

The research team phase involved participation in a current Australian project, entitled Assessing individual learning in teams: Developing an assessment model for practice-based curricula in engineering. The project, funded by the Australian Learning and Teaching Council, has developed a strategic framework for assessing individual student learning in team-based subjects. This framework is currently being piloted in undergraduate engineering courses in four Australian universities, and is comprised of a number of processes, one of which is co-creating learning intent between students and academic staff (Howard and Eliot, 2011).

The “teacher / individual researcher” phase comprises the majority of the current paper and is characterised by a number of “decision points”, at which the researcher makes a choice between directions in which the research could head or in the subject of study and so on. In most cases, the decision point determines the subsequent nature of the research and its outcomes.

The first decision point required that an element of the framework be chosen for deeper exploration. Co-Creating Learning Intent (CCLI) was selected primarily because it is a concept of deep interest to the author, and is fundamental to the principles of student-centred learning.

The second decision point related to the design of interventions and responded to the question “What are the theoretical underpinnings that will inform the design?” In this case, the dilemma was that while theory of DBR indicates that designs must be grounded in theory, there is no prior theory about CCLI. To identify theories that informed understanding of Co-Creating Learning Intent, the author drew on theories from a disparate range of disciplines that highlighted what must be incorporated into the intervention. Ultimately the theoretical scaffold developed included theories about co-creation (Ramaswamy and Gouillart, 2010), learning (Blumer, 1969; Golub, 1988; Johnson and Johnson, 1989; Johnson et al, 1990; Schön, 1983 – to name but a few) and intent (or conation) (Assagioli, 1974; Confessore and Park, 2004). However, it is not the purpose of this paper to discuss these theories in depth.

The third decision point was about the design of the actual intervention - in this case, a number of teaching and learning activities. In response, the following interventions were designed:

1. clearly stated learning outcomes / graduate attributes – an important element of this was that there was an on-going dialogue throughout the semester about what
the outcomes actually meant, and about what evidence was required to be gathered;

2. “learning buddy” – students in the first class chose a “learning buddy” with whom they developed a learning contract that set out their learning objectives for the semester. Every week, 30 minutes at the beginning of class time was set aside for learning buddies to get together to focus on their intent for that day’s class, and to reflect on their learning over the past week;

3. reflective journal – students were required to keep a weekly reflective journal: an assessable element was that they were required to write a critique of their reflections at weeks 6 & 12.

4. peer discussions in class;

5. co-created assessment criteria.

The fourth decision point, concerning the evaluation of the interventions, lead to the questions “What do I evaluate?” and “How?” In traditional educational research, “interventions” (such as instructional programs, texts or teaching policies) are measured against established standards (Worthen et al, 1997). However, DBR takes this further and regards successful interventions as the joint product of both the designed intervention and the context. Its ambition is to inquire more broadly into the nature of complex educational systems.

This in turn led to the final decision point of the iterative cycle, namely “How does my experience inform my understanding (of Co-Creating Learning Intent) and continue to build the theory (about both Co-Creating Learning Intent and the design-based research process)?”

Conclusions and future research plans

Design-based research has been found to be an extremely useful methodology to employ in the context of this case study, namely piloting a strategic framework for assessment developed by a research team. Although superficially similar to “action research” (McNiff and Whitehead, 2006), DBR is grounded in theory and has an explicit ambition to build on and develop theory. In the author’s experience as presented here, DBR has enabled manageable parts of a very complex system to be investigated, providing both theoretical insights and practicable interventions. Indeed it would appear that DBR may prove to be a key approach in the process of embedding / embodying complex frameworks that emerge from big projects, which are often so extremely generalised and abstract that they struggle to get implemented effectively.

Although the work described here is related to the application of DBR to a specific exploration of co-creating learning intent, the author concludes that the DBR process illustrated in Figure 1 could be applied effectively not only to other aspects of self-directed and team-based learning, but indeed to large areas of curriculum design. In this case, the research-team phase becomes the curriculum development phase, and there is greater emphasis in the next phase on the role of teacher. It is likely that the process can be
applied even more broadly, to investigating, and providing theoretical insights into, almost any aspect of learning theory.

As a research methodology, DBR needs standards whereby its effectiveness can be judged, to help guide and define the scope of subsequent iterations. Moreover, it will be important to find ways of accommodating the influence of contextual variables that arise in shaping the desirability, practicality and effectiveness of designs (Dede, 2004). Further, it will only be by adopting DBR more widely that the stranglehold that more traditional, reductionist, quantitative, „scientific“ approaches have on research will be loosened. The whole field of integrating DBR approaches from across different disciplines also beckons.

The author proposes to explore in greater depth the decision points and other components of the process illustrated in Figure 1, to develop the application of DBR to engineering education in a wider context, and to engage in an in-depth study of Co-Creating Learning Intent, which has emerged from the present work as a key element, concept and theoretical construct in student centred learning.

References


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Investigating the nature of thing orientation

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Abstract: One means of investigating the unique relationship between engineers and things is using thing orientation. Research has demonstrated that engineering students display higher levels of thing orientation than students of other majors, and that thing orientation is strongly predictive of persistence in engineering. However the nature of thing orientation as a psychological disposition and the mechanism through which it acts are poorly understood. This study attempts to further define thing orientation by exploring its relationship to better understood psychological constructs. Using an electronic survey, data were collected from 300 engineering students about their personality traits, dispositions and abilities. It was found that while thing orientation was slightly related to a few of these traits, it clearly differs significantly from these constructs. This together with its predictive ability indicate that thing orientation represents a higher order trait important for engineers and requires further study.

Introduction

Artefacts or objects, those things that are human made, are arguably central to engineering being both the products of engineering activity and the tools through which this activity takes place. Engineers have a special relationship to artefacts, interacting with them in ways no other profession does from conception and creation, through maintenance and disposal. Through these processes engineers control knowledge of and access to these artefacts and communicate ideas and intentions through them.

This special relationship between engineers and artefacts has been recognized in several ways. For example a study by Brereton (1999) found that artefacts are especially important in engineering learning activities. Her study found that engineering learning activities commonly include artefacts and display high levels of interaction between theory, proposed design and the artefacts provided. A second study by Brereton and
McGarry (2000) extended this observation finding that engineering designers rely heavily on tactile and visual cues for design and commonly use physical props to think through design problems and communicate ideas. Objects are also used to model concepts, illustrate thinking, spark ideas, test assumptions, and prototype solutions.

Other studies go further and argue that the role of artefacts in engineering goes beyond scaffolding design work. In their paper on the role of artefacts in design work, Perry and Sanderson argue that design work can no longer be adequately conceptualized in terms of individual “intelligence”, nor as a linear process with a set of design stages. It is rather as a situation in which joint, co-ordinated learning and work practices evolve, and in which artefacts help to mediate and organize communication. Therefore artefacts form a part of the process of product design whilst at the same time orienting the participants to the co-operative aspect of their work and revealing information about their “location” within the process, and who has acted on them (1998). Another look at the relationship between engineers and artefacts using situated cognition theory to examine product dissection found that the presence of artefacts increased creativity among engineers (Grantham et al, 2010; Dalrymple, 2011).

Artefacts obviously play a complex, extremely important role in engineering and engineers have a unique relationship to them. This special relationship is one of the reasons students commonly express to explain their interest in engineering; many students when asked why they chose to pursue engineering speak of “wanting to take things apart” or “being good with their hands”. It follows then that there might be certain personality traits or dispositions that we will refer to as “perceptuality” within these individuals that attracts them specifically to things and consequently engineering. Attempts have been made to define this trait, for example through measuring mechanical and spatial aptitude, but arguably these are facets that do not fully define it. In this research we propose that thing orientation is another facet of this construct and try to investigate thing orientation and situate it within the set of acknowledged individual differences.

**Background**

Our approach is based on the assumption that artefacts are in fact representations of mental processes; so in essence artefacts are human thought expressed through material transformation (Kaptelinin & Nardi, 2009). Therefore these artefacts are not neutral but implicitly or explicitly communicate the experience, imagination and purpose of their creator and are part of an activity system (Vermaas & Houkes, 2006). Thus artefacts are tools of inter-subjectivity (linking one mind to another), bringing together both individuals and the environment.

While artefacts are tools of inter and intra personal connection, it must be recognized that they are outside of the person and belong to the environment in the person-environment dichotomy. However, because of their functional nature, they form a special class within the environment that here are referred to as “things”. It is therefore logical when pursuing an investigation of perceptuality, to examine both the person and the thing. Investigations of this dichotomy have been a recurring theme starting with Thorndyke in 1911 and
proceeding through psychological, sociological, organizational and vocational literature (e.g. Barron-Cohen, 1980; Cattel & Drevdahl, 1955; Lippa, 1998; Little, 1968; Sarris, 1994). Prediger in his 1982 paper found a person-thing dimension of task performance preference underlying Holland’s original six factor model of vocational interest. This person thing dimension has consistently been found to have the largest effect sizes especially along gender and major lines (Su, Rounds & Armstrong, 2009).

Little (1974) went further and created an instrument to measure this person or thing focused task performance preference labelling them person and thing orientation. This instrument was then refined and validated by Graziano et al (2010). Application of this instrument with students from majors ranging from psychology to life sciences, engineering, education etc. has demonstrated several things: men are generally higher in thing orientation than women; women are higher in person orientation than men; students in highly person focused majors such as education and nursing display high levels of person orientation; students in science and technology focused majors display higher levels of thing orientation, engineers consistently display the some of the highest levels of thing orientation; thing orientation is consistently strongly predictive of persistence in engineering (Graziano et al, 2008). Though this research demonstrates the importance of thing orientation among engineers, the nature of thing orientation and the mechanisms through which it acts are unclear. Therefore this study seeks to investigate the nature of thing orientation.

**Methodology**

The central question of this study is “what is thing orientation?” When seeking to understand a psychological construct there are two major approaches. The Aristotelian approach assumes that the true nature of a construct can be revealed by finding an instrument that directly measures it. The Galilean approach, on the other hand, assumes that behaviour is context dependent resulting from the interaction of several factors. This approach therefore looks for consistent interactions among variables that explain the behaviour. It is this second approach that is used in this study. This study uses interactions between thing orientation and other variables to reveal the nature of thing orientation. The differential orientation along the person-environment dichotomy in the psychological, sociological, organizational and vocational literature has overwhelmingly been examined from a personality trait/dispositional perspective. Therefore, in our investigation, we compared person and thing orientation to the major personality traits. Spatial and mechanical aptitude were also measured to investigate whether they might be related to thing orientation.

Data were collected from approximately 300 engineering students (123 female) in their fourth, and for many, final year of college at a large Midwestern American university. Data were collected using an electronic survey sent out to students. This survey contained validated scales measuring a selection of psychological variables using Likert type items. These included the Big Five personality traits i.e. conscientiousness or a tendency to disciplined dutiful action with the goal of achievement, agreeableness or a tendency to be compassionate and understanding towards others, neuroticism or a tendency towards...
negative emotions or emotional instability, extraversion or the tendency to seek interaction and stimulation from others, and openness or an appreciation and desire for ideas and new experiences and a tendency towards adventure (John & Srivastava, 1999). It also included measures of traditional masculinity and femininity, agency or the striving for elevation and social dominance, communion or the striving for collaboration and the preservation of social bonds (Ward et al., 2006). The survey also measured individuals orientation towards mechanisms of social influence i.e. rule orientation wherein an individual is oriented towards compliance with authority, role orientation where an individual seeks out people and things that are attractive to identify with, and value orientation where an individual searches for values that match their own (Kelman, 2006). Finally, the survey measured students’ mechanical aptitude or intuition for the function of mechanisms and machines and spatial aptitude or understanding of spatial relations and their person orientation or orientation to interpersonal interaction and thing orientation. These scales were reduced to provide a score on each of these variables for each student. Correlations between these scores and person and thing orientation were then calculated.

**Findings and Conclusions**

The analyses described above revealed that person orientation was strongly related to other variables involved in interpersonal interaction i.e. openness (r = .18, p < .001); extraversion (r = .35, p < .001); conscientiousness (r = .11, p < .001); agreeableness (r = .25, p < .001); femininity (r = .45, p < .001); and communion (r = .44, p < .001). It was also less strongly correlated to masculinity, role and value orientations and negatively correlated to agency (Table 1). Thing orientation on the other hand was only significantly positively correlated with openness (r = .37, p < .001) and negatively correlated with neuroticism (r = -.16, p < .001).

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<th>Variable</th>
<th>Person Orientation</th>
<th>Thing Orientation</th>
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<td>.37**</td>
</tr>
<tr>
<td>Extraversion</td>
<td>.35**</td>
<td>-.07</td>
</tr>
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<td>Conscientiousness</td>
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<td>-.06</td>
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<td>Neuroticism</td>
<td>.05</td>
<td>-.16**</td>
</tr>
<tr>
<td>Agreeableness</td>
<td>.25**</td>
<td>-.06</td>
</tr>
<tr>
<td>Masculinity</td>
<td>.18**</td>
<td>.08</td>
</tr>
<tr>
<td>Femininity</td>
<td>.45**</td>
<td>-.08</td>
</tr>
<tr>
<td>Agency</td>
<td>-.21**</td>
<td>.15</td>
</tr>
<tr>
<td>Communion</td>
<td>.44**</td>
<td>.02</td>
</tr>
<tr>
<td>Rule Orientation</td>
<td>-.19</td>
<td>-.11</td>
</tr>
<tr>
<td>Role Orientation</td>
<td>.36*</td>
<td>-.11</td>
</tr>
<tr>
<td>Value Orientation</td>
<td>.47*</td>
<td>.17</td>
</tr>
<tr>
<td>Mechanical Aptitude</td>
<td>-.12*</td>
<td>.06</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------</td>
<td>-----</td>
</tr>
<tr>
<td>Spatial Aptitude</td>
<td>-.14*</td>
<td>.08</td>
</tr>
</tbody>
</table>

$N \sim 300$, **$p < .001$, *$p < .05$

Table 1: Correlations among thing orientation and other variables

Examination of person orientation reveals that it indicates a preference for interpersonal interaction and fits well within the Big Five personality paradigm being strongly positively correlated to agreeableness, conscientiousness, and extraversion. It can be said to be a facet of the same set of traits. However, thing orientation does not display this coherence. It is only positively correlated to openness to experience. This suggests that thing orientation represents a construct that may not be directly accessed by any of the variables identified here providing further evidence that it is an aspect of personality that has not been adequately explored; though it certainly merits further investigation because of its strong, consistent ability to predict engineering interest, persistence and self-efficacy.

These results would also seem to suggest that the higher order construct represented by thing orientation while related to artefacts, is not purely an artefact attraction or ability to manipulate. The explanation for this could be that artefact interactions are not themselves the focus of thing orientation but undertaken in pursuit of intersubjectivity. It follows then that the essence of thing orientation may lie not in the artefact interaction itself but in the processes that can be accessed through the artefact i.e. the process that is embodied in how the artefact was made, works, or what it is used for. Therefore thing orientation is arguably a process orientation rather than an entity orientation.

**Future Work**

Further research is needed to more clearly investigate the scope of thing orientation. This research is limited to a sample of engineering students from one cohort of one university. Future investigations should explore a diverse population to determine whether the observed interactions are stable. Furthermore, a larger sampling of traits should be explored to determine whether there are any others that relate to thing orientation.

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Using Inquiry-Based Activities to Repair Student Misconceptions Related to Heat, Energy and Temperature

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Abstract: This study examines the effectiveness of inquiry-based activities for addressing student misconceptions related to four concept areas in the thermal sciences that have been identified as both important and difficult for students to master: (1) temperature vs. energy, (2) factors that affect the rate vs. the amount of energy transferred, (3) temperature vs. perceptions of hot and cold and (4) the effect of surface properties on thermal radiation. Students’ conceptual understanding was assessed using the newly developed Heat and Energy Concept Inventory (HECI). In the control sample, student performance on the overall HECI improved from 49.2% correct to a post-instruction performance of 54.5% correct. Using inquiry-based activities, the mean performance on the HECI improved from 46.6% correct prior to instruction to a post performance score of 70.1%. Significant learning gains were found in each of the targeted concept areas when the activities were used.

Introduction

There is broad recognition that meaningful learning requires that students master fundamental concepts. Understanding concepts and the connections among concepts is one of the primary distinctions between experts and novices (Bransford et al., 2000; Chi, 2006;). Conceptual understanding is also a prerequisite for students to transfer what they have learned in the classroom to new settings, something that is arguably among the most significant goals of an engineering education.

While there is little disagreement about the importance of conceptual learning, a wealth of evidence drawn from decades of research in the sciences (Lightman et al., 1993; Laws et al, 1999; Chi et al, 2005; Reiner et al., 2008) and a growing literature in engineering (Prince et al., 2010; Prince et al., in review; Krause et al., 2003; Steif et al., 2005; Miller et al, 2006; and Streveler et al., 2008) demonstrates that students generally enter our classrooms with misconceptions and that traditional instruction is often ineffective for
promoting sizeable conceptual change. Research, much of it in the sciences, has successfully demonstrated that a range of student-centered instructional techniques can significantly improve students' conceptual learning gains (Hake, 1998; Laws et al., 1999; Reddish et al., 1997; and Mazur, 1997). There is a small but growing body of literature in engineering that supports similar conclusions (Prince et al., 2006, 2009).

Several factors explain why engineering education has not yet fully capitalized on the research, primarily in physics, for addressing student misconceptions. These factors include (1) the unfamiliarity of the relevant education literature to many engineering educators, (2) the lack of concept inventories with good estimates of internal consistency and validity that address core engineering areas and (3) the lack of tested educational materials in engineering similar to those that have been developed and tested in physics. However, significant progress is happening related to each of these issues. The lack of established educational materials specifically designed to repair important misconceptions in the core disciplines of engineering is arguably the predominant missing piece.

The study examines the extent to which inquiry-based activities promote conceptual learning gains in the 4 concept areas in the thermal sciences that have been identified as both important and difficult for students to master (Nottis et al., 2009; Prince et al., 2009; Streveler et al., 2003). Those concept areas are (1) temperature vs. energy, (2) factors that affect the rate vs. the amount of energy transferred, (3) temperature vs. perceptions of hot and cold and (4) the effect of surface properties on thermal radiation. In addition, the study examines the effectiveness of the activities for developing students' transfer their co

While conceptual change is difficult, a number of approaches have shown promise for promoting conceptual learning relative to traditional instruction. Most of those approaches are active engagement methods and many are inquiry-based. Bernhard (2000) provides a good overview of the range of inquiry-based approaches that have been developed for physics education including Physics by Inquiry, Peer Instruction, Real Time Physics, Tools for Scientific thinking and workshop Physics. Prince and Felder (2006, 2007) provide extensive evidence that a variety of inquiry-based instructional methods are effective for promoting conceptual understanding as well as additional educational outcomes. The framework adopted for the activities presented in this study drew heavily on the Workshop Physics model, the defining elements of which (Laws et al., 1999) are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Elements of Inquiry-Based Activity Modules (Laws et al. 1999)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Use peer instruction and collaborative work</td>
</tr>
<tr>
<td>(b) Use activity-based guided-inquiry curricular materials</td>
</tr>
<tr>
<td>(c) Use a learning cycle beginning with predictions</td>
</tr>
<tr>
<td>(d) Emphasize conceptual understanding</td>
</tr>
<tr>
<td>(e) Let the physical world be the authority</td>
</tr>
<tr>
<td>(f) Evaluate student understanding</td>
</tr>
<tr>
<td>(g) Make appropriate use of technology</td>
</tr>
<tr>
<td>(h) Begin with the specific and move to the general</td>
</tr>
</tbody>
</table>

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This approach is similar to that proposed by others (Hausfather, 1992, Thomas et al., 1995) and has extensive empirical support (Laws et al., 1999; Thacker et al., 1994; Thomas et al., 1995) Letters in parentheses in the following description of the activities refer to the elements of Table 1 in order to demonstrate the consistency of the approach employed here with the methods described in Table 1. Students were put in teams (a) and asked to predict what would happen in a number of scenarios (c). The students were then given physical experiments and/or computer simulations to test their predictions (b, e, g), after which they were asked to discuss how their thinking had changed if their predictions did not match reality. All the questions were conceptual in nature (d, f), using technology where appropriate (g). At the end of the specific activities, students were asked to step back and generalize what they had learned from the specific experiments and in some cases were asked to extend that knowledge to a novel application in order to determine if the learning was transferable to a new situation (h).

**Methodology**

This exploratory study examined the effect of 8 inquiry-based activities for improving students' conceptual understanding in 4 targeted concept areas using the newly developed Heat and Energy Concept Inventory (HECI). The instrument was designed specifically to assess these specific concept areas and has demonstrated acceptable levels of internal consistency reliability and content validity (Prince et al., 2011).

A quasi-experimental design with intact groups was used to assess learning gains. The two groups were a test group that were given the activities and a control group that was not. Participants completed a computerized version of the HECI prior to and after instruction. Measurements for the control group assessed pre/post changes on the HECI under normal conditions, that is, without the use of the activities. Student learning gains for this sample were compared to gains found for a test sample of students who experienced the activities in their heat transfer course.

Descriptive statistics examined changes in knowledge, as measured by the mean scores of participants on the entire concept inventory as well as in each conceptual area sub-test. Independent t-tests were used to examine the differences between pre and post-test scores of the two groups (e.g., difference in pre-test scores of control and test groups). Dependent t-tests were used to examine pre-post learning differences for both the control group without activities and for the test group with activities. Normalized gains were also used to compare the groups. In addition, effect sizes, using Cohen's d, were calculated to show the magnitude of the difference between the means of each group. The appropriate measure of effect size for t-tests is Cohen's d (Cronk, 2010).

The HECI was administered as a pre-test of existing knowledge to a control group of 373 undergraduate engineering students at ten different universities or colleges. The concept inventory was used in 11 course offerings, two of which were offered at the same institution in two different semesters. Of the 373 respondents, 344 completed the concept inventory again after instruction in a heat transfer course. The test group consisted of a sample of 129 students at 4 undergraduate institutions. The HECI was administered as a
pre-test of existing knowledge to this group. Of the 129 respondents, 116 completed the concept inventory again after instruction that included administration of the inquiry-based activities. Each activity was designed to incorporate each of the elements of inquiry-based activities as defined by Table 1. There were 8 activities tested in this study, two targeting each of the four concept areas of the HECI. Students at each institution used all of the activities.

Results

An independent t-test showed no significant difference between the test group using the inquiry-based activities and the control group on the total pre-test scores, \( t(487) = 1.454, \ p>0.05 \). Paired samples t-tests showed that there was a statistically significant improvement from pre- to post-test scores for both the test and the control groups. A summary of the results as assessed by pre/post measurements using the HECI for both the control and test groups is shown in Table 2. As can be seen from the table, while student learning gains in the control group were statistically significant, they were modest \((t(336) = -7.737, \ p<0.01, \ d=0.42)\). The magnitude of the effect size suggests a moderate effect. By contrast, the significant improvement with inquiry-based activities was larger (mean score of 46.1% on the pre-test to a mean score of 70.1% on the post-test), \((t(89) = -13.39, \ p<0.01, \ d=1.41)\) and the effect size indicates a very large effect. Fraenkel and Wallen (Fraenkel and Wallen, 2009) have recommended that an effect size of 0.50 or greater should be interpreted "as important" (p. 244).

Table 2. Mean Pre/Post Performance Data by Content Area, With and Without Activities

<table>
<thead>
<tr>
<th>Content Area</th>
<th>Mean Score, Control (no activities)</th>
<th>Mean Score, Test (w/ activities)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Test N = 373 Post-Test N = 344</td>
<td>Pre-Test N = 116 Post-Test N = 103</td>
</tr>
<tr>
<td>Temperature vs. Energy</td>
<td>52.8% 54.7%*</td>
<td>34.8% 68.5%**</td>
</tr>
<tr>
<td>Temperature vs. Perceptions of Hot or Cold</td>
<td>61.2% 69.4%**</td>
<td>59.1% 77.4%**</td>
</tr>
<tr>
<td>Rate vs. Amount</td>
<td>36.9% 42.6%**</td>
<td>51.7% 85.9%**</td>
</tr>
<tr>
<td>Thermal Radiation</td>
<td>44.4% 49.5%**</td>
<td>39.5% 68.7%**</td>
</tr>
<tr>
<td>Overall</td>
<td>49.2% 54.5%**</td>
<td>46.6% 70.1%**</td>
</tr>
</tbody>
</table>

* Statistically significant at the \( p < 0.05 \) level.

** Statistically significant at the \( p < 0.01 \) level.

One conventional measurement used in much of the conceptual change studies involving physics students is the normalized gain, defined as the improvement in student scores normalized by the possible gain. For example, the normalized gain for students in the control group is 10.4%, calculated by looking at the measured gain of 5.3% (54.5%-49.2%) divided by the total possible gain of 50.8% (100%-49.2%). This can be compared to a
normalized gain of 44% with activities. A chart comparing normalized gains on the instrument as a whole as well as for each of the sub-categories of the HECI is shown in Figure 1. The data shows that the activities improved student learning gains in each of the four targeted concept areas as well as for the overall. These gains are significant, both statistically and in absolute terms.

![Figure 1: Effect of Activities on Learning Gains](image)

The study also examined the impact of inquiry-based activities on students' ability to transfer knowledge to different contexts. Each question on the HECI was characterized by content experts as requiring either near or far transfer of conceptual learning depending on the degree to which the question related to the inquiry-based activity. Results suggest that the activities promoted both near and far transfer of learning gains, but that the activities were more effective for promoting near transfer. Student scores improved from a mean of 35.2% to 73.6% with an effect size of 1.54 for questions requiring near transfer and from a mean score of 53.4% to 72% with an effect size of 1.33 for questions requiring far transfer.

Finally, an independent t-test was used to examine the differences in post-test scores between the control and the test (inquiry activity) groups. Effect sizes were also calculated to characterize the magnitude of the difference. The test group scored significantly higher than the control group on the post-test (t=-8.33, p<0.01, d=0.88). The magnitude of the effect size as measured by Cohen’s d indicates there was a strong effect.

**Conclusions and Future Work**

This study builds on earlier research in a number of ways. Consistent with a large body of literature, the data from the control group demonstrates that students have significant misconceptions about heat, energy and temperature and that these misconceptions are
frequently robust or resistant to change through conventional instruction. The modest learning gains found for the control group support that finding. At the same time and again consistent with a large body of literature in the sciences, it has been shown that the use of inquiry-based activities can significantly increase student performance on measures of conceptual understanding, even in those cases that are resistant to change through conventional instruction. Again, the significantly improved student performance, both in the aggregate and for each of the targeted concept areas of the HECI, supports this assertion. Taken as a whole, this work contributes to our understanding by adding to what is at present a small data-base of the effectiveness of such activities with undergraduate engineering students.

While these results are very encouraging, there is a need for significant future analysis. We are in the process of how effectively the activities promote conceptual learning gains immediately after their completion compared to student performance on the concept questions several weeks after the activity. In addition it would be beneficial to have additional measures of students' conceptual learning, drawn from additional venues such as concept maps or semi-structured student interviews.

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Using complexity theory to develop a new model of student retention

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Abstract: This study aims to develop a deeper understanding of the issues affecting student retention in higher education, and the relationships between them. In this paper we explore the use of Complexity Thinking, in conjunction with Exploratory Factor Analysis and Multidimensional Scaling and how these provide different insights into student retention that are not provided by existing models. The vehicle for our pilot analysis is a small data sample collected from undergraduate engineering students at a traditional Swedish university. This analysis shows that issues affecting student retention could more helpfully be viewed as nested, interconnected systems, in which certain components are more influential than others, rather than in the linear ways that existing models tend to encourage.

Introduction

Student retention has long been an area of research in higher education. This research has led to models of student retention that are widely used (Bean 1982, Tinto, 1997). Although “complex” aspects of the relationships between the variables in these models have been acknowledged by many workers in the field, they have not been explicitly incorporated into these models. To overcome the linear relations between variables implicit in these models, we are proposing a different approach to modelling student retention by drawing on complexity thinking as a conceptual framework.

We chose to analyse factors affecting student retention in a traditional Swedish university, using mostly engineering students, because of international concern over the critical increases in demand for new engineers and scientists, coupled with a decline in interest in
careers in science and technology in many countries, particularly in the developed world (CSEPP, 2007, OECD, 2009).

Moreover, in many countries the percentage of students who manage to successfully complete their degrees in engineering programmes in minimum time, or at all, is decreasing (CSEPP, 2007, OECD, 2009). It is our aim in this study to develop a model of student retention that will be able to inform such institutions of the most critical features affecting student retention, together with how they are related to one another, to enable them to make better decisions with regard to improving retention.

**Research Questions**

The aim just outlined leads to the following research questions:

1. Can the use of complexity thinking provide helpful insights into the relationships between the variables affecting student retention in programmes such as engineering, which are not provided by current models of student retention?

2. Can these insights help us to improve the retention in engineering programmes?

We have undertaken a pilot study that will help us to address these questions.

**Theoretical Framework: Complexity thinking**

In this section, we will present the concepts that we draw upon from complexity thinking to produce a more powerful and holistic modelling system of student retention. Complexity thinking aims to describe and understand complex systems and their capacity to show order, patterns, and structure. Especially important is how these orders, patterns and structures seem to emerge spontaneously from interactions between components of systems, as well as between them and the external world.

Complexity thinking is often pitted against "classical science", which is, in turn, portrayed in terms of efforts to condense phenomena into their simplest components. However, to obtain a reasonable portrayal of a complex phenomenon, an understanding of the properties of the components alone is not sufficient. What is central in describing or understanding a complex system is identifying the components, their interactions, and what emerges from the complex system: its behaviours, properties and structures, or the "structuring structures" of the complex system (Bourdieu, 1984).

**The structure of complex systems**

Three types of network structures may be identified:

1. Centralized networks have a single central node with every other node connected only to that central node. Centralized networks spread information effectively, but they are vulnerable to break down due to the dependency on the central node.
2. Distributed networks, where all nodes have the same connectivity in the network. Distributed networks are robust to break downs but inefficient in spreading information.

3. Decentralized networks, in which there are multiple connections between nodes. When a highly connected component is removed, then the whole system will suffer damage. The system will remain stable, however, with the removal of any of the many less connected nodes.

Complex systems have a decentralized network structure, which means that there are some components or nodes that are much more connected than others. Components within a complex system can be considered to be complex systems themselves, thus complex systems are nested. Each level of such nested complex systems exhibits similar structures and dynamics but operates within different time-scales and/or at different levels of analysis (such as the level of an individual, or of a group of individuals, or of a particular culture, or of all human beings). For example, mathematics learning-for-teaching has been modelled as several nested systems: subjective understanding, classroom collectivity, curriculum structure, and mathematical objects (Davis and Sumara, 2006), with subjective understanding having a faster rate of change than mathematical objects.

Dynamics of complex systems

One key aspect of complex systems is that they are continually changing as the components in the system interact with the external environment and with one another. This means that complex systems are adaptive and self-organize; properties, behaviour and structure all emerge without an external system or an internal “leader system” that controls the complex system.

Components of complex systems interact mainly locally via neighbour interactions, which can fuel processes that lead to emergence such as positive feedback (which tends to amplify properties, behaviours and structures) and negative feedback (which tends to dampen them). Depending on how “connected” each component is with other components within the system, the positive or negative feedback can be greatly amplified or dampened. Decentralized network structure is a key element in facilitating emergence in complex systems (Davis and Sumara, 2006).

Methodology

Data was collected from two sources: student retention and demographic information was obtained from student records, and a questionnaire with 29 questions was developed to explore influences on student retention. The questionnaire was largely based on the work of Cabrera, et al. (1992a, 1992b, 1993). Students answering the questionnaire were asked to mark their level of agreement with 29 statements on a five-point Likert scale. Each separate piece of information (5 items of record data and 29 question responses) was a component in the analyses, giving 34 components altogether.

As a preliminary study to verify our approach, the questionnaire was administered to 51 students (39 of whom were in two Engineering Programmes, and the remaining 12 in a

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Physics Programme) participating in a second semester Physics course at a traditional Swedish university. Re-enrolment in the second year (third semester) was used as a measurement of student retention (it was 82.4%).

Complexity thinking is not characterized by a particular method but by a methodological perspective that employs a range of methods to study complex phenomena (Davis and Sumara, 2006). The following tools were applied to the analysis of the structure and dynamics of the complex system of student retention: exploratory factor analysis, multidimensional scaling and network theory.

**Exploratory factor analysis**

Exploratory factor analysis is used to study patterns and order within complex data by comparing angles between points in a multidimensional space. Exploratory factor analysis identifies those components that have “commonalities” by using the covariance between the components (Kim and Mueller, 1978). Components with higher covariance are grouped into a number of factors, with the number being determined by the groupings that arise.

Our analytical tool was the Statistical Package for the Social Sciences, SPSS (Predictive Analytic SoftWare, PASW, version 18.0). Our starting point was the normalized matrix of the component data.

**Multidimensional scaling**

Multidimensional scaling is a good way to determine the relative proximity of components to one another as it offers a way to calculate the distances between points of data in multidimensional space.

Components that have a high relative closeness to other components can be regarded as being connected and within each other’s “zone of influence”. The results of this analysis are used to create a representation of the network structure of the complex system. The components may be seen as nodes (vertices) linked by edges (connections/relationships between nodes), which form a basis for visualization and allow for measurements of component interaction through the use of network theory.

**Network theory**

The orienting emphasis in network theory is "structural relations" (Knocke and Yang, 2008). Network theory is thus a powerful analytic tool to explore and illustrate the structure connectivity that was generated using multidimensional scaling.

**Network theory concepts**

A *path* is a way through a sequence of nodes that begins with a starting node, follows adjacent nodes through the network and ends at an end. When every node in the network is reachable (i.e., a path exists between every node) the network is connected. If there are many paths between two nodes, the *shortest path* between them is the one with the fewest
connections made through other nodes (Freeman, 1978). Visualization and analysis of networks, and therefore complex systems, is made possible by using these constructs of network theory.

**Network measurements and interpretation**

We assumed that we had an undirected network where the connections between the nodes did not have a specific direction of influence. Analysis of the created network was done by using Statnet working with the "R" statistical computing and graphics program (Handcock, et al, 2003).

Identification of “important” nodes was done by calculating each node’s *centrality*. *Closeness centrality* is an ordinal measure of how “close” every other node is, and it is calculated through finding the shortest path between nodes (Bernardsson, 2009). Information can be spread to the whole network more effectively via nodes with high *closeness centrality* (Freeman, 1978). *Betweenness centrality* is the frequency that one particular node is a part of the shortest path between every other node (Bernardsson, 2009). Nodes that are more frequently a part of the shortest path between nodes may be interpreted as having a high degree of “control of communication” in the network (Freeman, 1978).

**Results**

Firstly, exploratory factor analysis was used to identify subsidiary complex systems within the broader complex system, and to demonstrate their nested structure. Secondly, multidimensional scaling and network analysis were used to show the connectedness of the components and to visualize how the components of the complex system interact with one another, and their closeness to one another.

**Exploratory Factor Analysis**

Exploratory factor analysis was used to identify the nested systems that make up the complex system of student retention through the identification of the factors within the overall system. Three measures were used together to achieve an appropriate correlation matrix of components in this analysis (Kaiser 1970). As a result, 11 components out of 34 were removed. These components were interpreted as having little effect on the system of student retention, at least for this pilot study. A scree test led us to choose a Four Factor solution for the model (Hofstede, 2001). Significant component loadings for each factor were identified by using a minimum loading of 0.32 on components (with one at 0.313).

The results of the exploratory factor analysis are given in Table 1, showing that there is overlap of components between the four factors, each of which is itself complex system. This illustrates the complexity and the nestedness of the whole system of student retention, and highlights the existence of neighbour interactions between the four nested systems, as well as that they have fuzzy boundaries.
Table 1: Loading from the exploratory factor analysis

<table>
<thead>
<tr>
<th>Component</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.E. credits within programme (HECwP)</td>
<td></td>
<td></td>
<td></td>
<td>0.542</td>
</tr>
<tr>
<td>Retention</td>
<td></td>
<td></td>
<td></td>
<td>0.934</td>
</tr>
<tr>
<td>Q1. Best university programme</td>
<td>0.788</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2. Family approval</td>
<td></td>
<td>0.472</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3. Satisfied with finances</td>
<td></td>
<td></td>
<td></td>
<td>0.836</td>
</tr>
<tr>
<td>Q4. Finances - focus on studies</td>
<td></td>
<td></td>
<td>0.833</td>
<td></td>
</tr>
<tr>
<td>Q5. Finances - teacher demands</td>
<td></td>
<td></td>
<td></td>
<td>0.796</td>
</tr>
<tr>
<td>Q7. Satisfied with curriculum</td>
<td>0.328</td>
<td>0.458</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q8. Close friends encouragement</td>
<td></td>
<td></td>
<td>0.580</td>
<td></td>
</tr>
<tr>
<td>Q10. I belong at my university</td>
<td>0.637</td>
<td>0.447</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q11. Future employment</td>
<td>0.464</td>
<td>0.390</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q12. My close friends rate this institution as high quality</td>
<td></td>
<td></td>
<td>0.313</td>
<td></td>
</tr>
<tr>
<td>Q14. Satisfied with experience of higher education</td>
<td></td>
<td>0.687</td>
<td>0.411</td>
<td></td>
</tr>
<tr>
<td>Q15. Easy to make new friends.</td>
<td>0.842</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q16. Right choice - university</td>
<td>0.683</td>
<td>0.399</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q17. Right choice - programme</td>
<td>0.758</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q19. It is important to get a degree from this programme</td>
<td>0.708</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q21. Initiation weeks</td>
<td>0.855</td>
<td></td>
<td>0.459</td>
<td></td>
</tr>
<tr>
<td>Q22. First year courses fit together</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q23. Previous knowledge</td>
<td>0.385</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q24. Clear educational trajectory</td>
<td>0.447</td>
<td>0.396</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q25. Faculty support</td>
<td>0.345</td>
<td>0.322</td>
<td>0.461</td>
<td></td>
</tr>
<tr>
<td>Q29. I intend to re-enroll</td>
<td>0.835</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Light grey shading denotes the components that have a loading above 0.32 in more than one factor.

Multidimensional scaling

Multidimensional scaling was used to visualize the network of components that influence student retention (using the same 34 components that were used for exploratory factor analysis). Network theory data analysis tools and complexity thinking were used to interpret the results.

Network Creation

Multidimensional scaling analysis was used on the data to determine the distances between components arising from this data. We used the multidimensional proximities between the components to identify components with relative closeness. Analysis continued as long as the network continued to resemble a decentralized network (Freeman, 1978).

At a cut-off proximity of 0.1 less than half the components remain connected to one another. Thus two components were considered to be within each others' “zone of influence” when their proximity was below 0.25. To retain the connectedness of the system Retention needed to have a higher cut-off of 0.5. Four other components dropped out of the network at the 0.25 level. Three particularly influential components (nodes) were identified. Figure 1 gives a visualization of the network showing connections between components, not their proximities.
Influential components

We used the closeness centrality and betweenness centrality scatter plot (Figure 2) to identify network components (nodes) that have a larger influence in the network. Nodes with high closeness centrality and high betweenness centrality both distribute information effectively throughout the system, and are in a position of “control” of the influence of other nodes on the system. Seven of these may be noted in Figure 2, along with two that have a relatively high betweenness centrality compared to others.

Discussion

This pilot study was too small to draw any conclusions about the nature of the four sub-systems identified through exploratory factor analysis. It is tempting to try to match these sub-systems with systems previously identified, such as the internal university academic, social, and support systems and the external system (Bean, 1980, Tinto, 1975, Tinto 1987),
but we believe that this would tend to limit what could emerge from an analysis such as this one.

From multidimensional scaling and the visualisation of the network shown in Figure 1, it is clear that this is a decentralized network. The three most influential components were each present in two of four factors in the exploratory factor analysis. The four components that dropped out of the multidimensional scaling and three of the outliers were among the eleven components that were dropped from the exploratory factor analysis. Thus both sets of analyses produce congruent results.

What this analysis has shown is that certain components influence the complex system as a whole.

This means that they should not be seen as direct linear influences, but as influences mainly through other components. Our analytic example shows how the structure and dynamics of the complex systems that influence retention can be brought to the fore empirically, and not only be alluded to.

**Recommendations**

These preliminary findings clearly need to be confirmed using a much larger data sample. We also recommend that a longitudinal study should be undertaken to establish how such results change as students progress in their studies. Application in a different context (for example, one where financial issues are important) also needs to be undertaken to validate this general approach.

Once we have a clearer idea of the complex nature of the issues and how they relate to one another, we would be in a position to make recommendations concerning how engineering education should respond, both in general and in particular contexts.

**Acknowledgments**

We would like to thank Staffan Andersson, Jannika Chronholm-Andersson and Anne Linder for the discussions which have been very rewarding throughout the development of this paper.

**References**


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Building leadership capacity of engineering academics in a leadership vacuum constructed within a participatory group to engage a professional body

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Abstract: This research investigates academic leadership at the frontline. It seeks to understand how and why engineering academics react to opportunities to develop and exhibit leadership. The analysis thus far indicates that there is an interdependent relationship between learned skills, traits, environment, and context in the way academics perceive, value, develop and exhibit leadership. The preliminarily findings are: Academics can operate within academia and be very successful without developing or exhibiting leadership; Most participants have industry experience and are engineering leaders, however, they chose not to exhibit leadership; Leadership vacuum alone does not necessarily encourage exhibition of leadership; Authority and structures were perceived as important; Academic context presents driving forces that inhibit developing and exhibiting leadership even in favourable environments; There is a self-selection process for academics to enter academia; Providing opportunities and changing the discourse of academics will enhance their leadership perceptions and behaviours.

Introduction

Ramsden (1998) described academic leadership simply as “...a practical and everyday process of supporting, managing, developing and inspiring academic colleagues” and that “...leadership in universities can and should be exercised by everyone, from the vice-chancellor to the casual car parking attendant. Leadership is to do with how people relate to each other.” Ramsden (1998) is assuming that leadership is inherent in organisations though it is rarely a matter of chance when change and improvements are made. Someone must have been influential. Ramsden (1998) points out, if leadership is to be effective, universities need to sidestep a series of errors associated with single models of academic excellence, teaching and research, human resource management, structure and process,
and to not overtly rely on regulations and processes but of leading in effective organizational culture and values. Southwell & Morgan (2009) states that academic leadership, and its impact on student learning is poorly researched. Though, they recognized that leadership does contribute to student learning based on limited empirical evidence available. It is from this apparent gap that this research is based on. The hypothesis is that engineering educators will be able to increase their leadership capacity via participatory activities with an external industry group. Furthermore, through a combination of professional development and collaborative activities, engineering educators will develop leadership capacity that will impact on student learning outcomes and experiences. It is with this rationale that this research attempts to understand why academics do and do not pursue and exhibit leadership when presented with opportunities to do so. The leadership opportunity is presented as an engagement with Engineers Australia (EA) to develop a new postgraduate program of which one of its objectives is to develop leadership in engineers. While engineering faculties have attempted to react to the changing nature of the engineering professional by collaborating with professional authority/industry (particularly at the Dean and associate Dean levels), and to cope with the declining staff-student ratios in often under-resourced faculties, employers and professional authority complain of graduates not being “work ready” and their ongoing continuous professional development are poorly catered for by the tertiary postgraduate sector (Nair & Patil 2008; Hicks 2009; King 2008a; 2008b). Some positive outcomes in selected pockets have recently arisen from collaborative work between individual disciplines and industry, often heavily sponsored by industry, such as the Australian Power Institute and Mining Education Australia [5]. On the surface, it seems that the respective bodies are attempting to address this concerns fairly collaboratively, though the resultant outcomes at the “coal-face” of engineering education is often quite independent due to a number of reasons. At the centre of the inhibitors is a difference of culture and values. At the interface of university and professional authority/industry, there are significant differences in the cultures and values in approaching the issue of lifelong learning of engineering professionals. Roberts (2007) identified that a variety of communities-of-practice have contemplated, even challenged, the relationship between academia and industry. Roberts said “... Academic purists believe that higher education has as one of its primary missions, the acquisition and dissemination of knowledge as an end in itself, focusing on acquiring knowledge, not necessarily on learning to use it...” Furthermore, it is argued that higher-learning institutions should be able to advance the thought-space without the pressures of commerce and capitalism (Roberts 2007; Etzkowitz 1998). Conversely, the professions who believe that it takes a “village of experts to train an engineer”, warn that the “Ivory Tower” is no longer an optimal or sustainable model for education (Roberts 2007; Etzkowitz 1998). In Bosley’s (1995) view, “the value of knowledge and research is related directly to the market value of the products it produces”. Roberts (2007) reiterated the perceived cultural divide by saying that “...individual research contributions, publications, and grant funding are often viewed as greater accomplishments than facilitating creative collaborations.” This leads to the research questions: When placed within a leadership vacuum that presents opportunities to develop and exhibit leadership, how will academics react within this vacuum? What are the barriers to leadership skill development for academic staff? How have participation
changed their leadership skills throughout the engagement with industry and the engineering profession? This paper presents data and preliminary analysis seeking a better understanding of how and why engineering academics react to opportunities to develop and exhibit leadership. It reports on the preliminary analysis of structured interviews with participants at the pre-intervention and post-intervention stages; surveyed data on knowledge and skills, their attitude, and behavioural frequency to leadership; data from discussions from an industry roundtable as part of the engagement; and, data from discussions from an internal academic roundtable with other academics from across the university.

**Literature Review**

The study of leadership is a diverse and commercialized field of research that is often linked to corporate executive training or coaching. A comprehensive literature review is a task that is wrought with danger particularly with literatures that preached “leadership” but are no more than life-stories and opinions. While some leadership frameworks encompass a broad range of trait attributes, others focus on specific attributes deemed most important to a great leader. Refer to Bryman (2004), Collins (2001), Kotter (1990) for further literature on corporate leadership. Bayne & Constable (2009) is a consolidated model of leadership. This model is based on a number of previous recognised literatures on leadership. This model suggest that leadership attributes are very much a combination of traits and skills, with some leadership elements that can be trained or learned, and some that are “born” or “grown-up” with. It is categorized into Intelligence, Emotional intelligence, Narrative intelligence, and Ethical intelligence. One must also ask the question whether leadership in academia is any difference to the corporate world of which many of the research output in the form of models are derived from, and how an organization and its value system will impact on the ability to nurture and exhibit these attributes. There have been recent studies into leadership in Australian academia such as Marshall (2006) and Holt & Palmer (2008) that should be referred to, but are mainly based on senior executive levels and departmental head levels, and a gap exists at the faculty or frontline level. In saying this, Scott et al (2008) is one notable work has been used as a reference guide for pursuing this research at the academic frontline (rather than at the management level). The study based its conceptual framework on academic leadership capability (personal, interpersonal, cognitive) and competency (generic and role-specific). The study has highlighted that formulating and implementing desired change is not an event but a complex learning and unlearning process for all concerned. It is a learning process because for those who are to deliver it, to do something new requires them to learn a „gap“ in their expertise. Such learning for change does not just happen; it must be directly assisted and deftly led. The approach, attitude and interpersonal strategies found to be most effective in helping staff make a desired change work closely with those used by the most successful higher educators with their students. This insight is important because it implies that the most effective leaders not only help their staff engage with and learn how to do necessary change, but they also set up an efficient and supportive environment that fosters productive engagement in such learning. Just as informal and formal elements of interacting with others can help or hinder student learning, so too relationships and
context are relevant for academics responding to and learning how to improve their work. The study has identified that many leaders find they have „no room to lead”; little time to lead or to think and operate strategically. Similarly, such cultural factors can create conditions where frontline staff finds they have „no room to teach” or to learn how to make desired changes. Its finding aligns well with studies of effective leadership in the most successful corporations in that effectiveness of leaders depends on the context around them. Majority of the literature surrounding academic-industry engagement are within the spheres of collaborative research, technology transfer and models that facilitate them. One such literature is D’Este & Patel (2007); they found that individual characteristics of researchers have a stronger impact than the characteristics of their departments or universities. They argue that by paying greater attention to the broad range of policy initiatives, it could contribute to building the researchers” skills necessary to integrate research and application. Though individual characteristics of academics are strong drivers for industry engagement, the context and environment that encourage developing and exhibiting such skills are equally critical. One relevant literature is Andrews et al (2005) studying the participation, motivations, and impediment to public outreach; they found the strongest motivating factors were a desire to contribute and enjoying their outreach experiences. Another motivating factor was the chance to improve their teaching and communication skills. Time constraints due to other, higher priorities, the lower value placed on outreach by institutions, and a lack of detailed information and planning of outreach opportunities were significant barriers to participation. They stated that institutions would have to embrace the third mission of universities: “service” as part of the systemic cultural and operational shift. One can correlate the same context and environment with this research.

Methodology & Methods

The theoretical framework in this research is based on the findings of Scott et al (2008). One critical theoretical concept worth mentioning is the approach, attitude and interpersonal strategies found to be most effective in helping staff make a desired change work closely with those used by the most successful educators with their students; within a specific academic context and their approaches to teaching in a particular subject that was taught in that context. Hence, academics were immersed in an environment to develop a leadership-based postgraduate program to develop and exhibit their own leadership capacity. Another concept is that the engagement with industry involves a complex learning and unlearning process for all concerned. A supportive environment that fosters productive engagement in such learning and “room to lead” is desired. Workload “buy-outs” were offered to the academic participants, and a dedicated collegial team was recruited and appointed. However, two scenarios were constructed to promote opportunities within a leadership vacuum; initially “unsupportive” environment without formal team structure and organisation, and later with a “supportive” environment with some structure and organisation, but still within a leadership vacuum. The leadership vacuum facilitated by one of the active researcher is critical to provide opportunities for the rest of the participants. This research is an action-based participatory research based on ethnographic and phenomenographic strategies with the one of the researcher actively
participating in the activities and others observing. However, a mixed methods approach was used for collecting data in the research. Both qualitative and quantitative data were collected, coded and preliminarily analysed with the assistance of NVivo software. Pre-intervention survey instruments based on McDaniel (2002), Smith & Wolverton (2010) and TurningPoint (2006) were applied (measuring the participants' knowledge, attitudes and values, behavioural frequency related to leadership), and one pre- and one post-intervention semi-structured interviews were applied. A leadership vacuum was constructed within the participatory group. The initial pre-intervention interview data was collected and analysed based on grounded theory and is presented. Free nodes were created from the initial coding process, and then tree nodes were accordingly created based on the themes that emerged from the interview data. The data interpretation and analysis was provided by two of the researchers separately (one sat through the interviews and the other not) with another researcher (who sat through the interviews) acting as an oversight providing additional input. The collective pre- and post-intervention interview data were later coded based on the leadership model described in Bayne & Constable (2009). The participatory group was presented with a task to develop a new postgraduate via engagement with EA without any structure to drive their assignment, and later after a few months, with appropriate structure and organisation to operate. A separate focus group was also used to collect data from other faculties across the university. The interview questions were formulated in the context of the assignment of the participants to establish a new leadership-based postgraduate program via engagement with a professional body. The pre-intervention questions were designed with 3 major themes; perceptions of industry and academia, perception of leadership within industry and academia, and perception of the leadership opportunities. The post-intervention questions were designed with 3 major themes; perceptions of the leadership traits and skills, self-assessment of leadership traits and skills, assessment of the leadership opportunities. There were seven engineering educators who participated over a 12 months period and all were interviewed. Five of the participants were engineering practitioners in various industry fields before pursuing their current academic career. The remaining two non-engineer participants are scientists teaching into engineering courses and did not have industry experience. One engineering academic is an engineering consultant who lectures on a part-time basis. The group is unique in the sense that the engineers did not have a “traditional” pathway into their academic career. The two science-based academics progress through their career as “traditional” academics.

**Data & Analysis**

The pre-intervention surveys are illustrated in figure 1 (knowledge and skills), figure 2 (attitudes and values), and figure 3 (behavioural frequency). The data suggests that most of the participants do have some appreciation of leadership in terms of context, content, processes and communication except for person 4 and person 5. However, when it came to their own assessment of their attitudes and perceived value of leadership, most participants including person 4 and 5 were pursuing leadership values, only person 7 was not pursuing leadership values. This is perhaps because most of the participants had prior industry experience. This is complemented by an analysis of their actual behavioural
frequency with person 7 actively avoiding leadership behaviours. This analysis of the participants suggests that the group should develop and exhibit leadership if given the opportunity to do so.

Figure 1: Baseline Self-Assessment in Leadership Knowledge and Skills (McDaniel 2002)

Figure 2: Attitude Self-Assessment for Leadership (Smith & Wolverton 2010)

Figure 3: Behavioural Self-Assessment for Collaborative Leadership (Turning Point 2006)

The pre-intervention interviews provided insights into the perceptions of leadership by engineering academics. The qualitative evidence does suggest alignment with previous studies into the academic leadership at the management levels. There are strong themes in the form of Nurture (Skills), Nature (Traits), Context (Environment) that straddle the spaces of the Academic (Person) and University (Organization). The findings were that almost all participants with the exception of one participant agree that leadership can be
nurtured, trained, and learned via various means including professional development but more so by practice. Hence, almost all agreed that life experience with interacting and managing people are key ingredient for nurturing leadership skills. The other finding of note is that the participants were quite sensitive to "authority" even though most have practiced as leaders in their professional careers. There was a strong and definite theme that leadership is a skill that can be learned and nurtured. According to the participants, the best way to learn such skills is to practice it. However, opportunities to practice though important should be accompanied by appropriate "on-the-job" professional development. Almost all agreed that this combination is needed for effective leadership capacity building. One non-engineer participant believes that leaders are "born". The participant based this perception of leadership on past experiences where many colleagues who "exhibited" leadership were "promoted". His belief is that "you either have it or you don't!", and that he believes that he is one of those individuals who do not possess any traits for leadership. The other non-engineer contradicted this mind-set and very much believes that leadership is learned, though the "ways" that one practice leadership may be dependent on one's traits. The engineers were of the perception that you need a combination of both skills and traits to be effective in leadership. All participants believe that life experiences play a significant role in structuring one's trait profile. Though contradictory at first, this seems to indicate that natural traits can be developed during maturation stages. Though important, the participants agreed that professional practice does play a minor role in developing one's traits. In this, the authors believe that some participants were referring to visible behaviours. After all, individuals can learn "ethics" but how can one learn to be "ethical". Most participants agreed that the life journey a person undertakes does mould one's traits. There were strong indications that there are major differences in how leadership are developed and practiced in academia versus industry. The participants believe that in academia, academics in general, do not have to exhibit or practice leadership in order to be recognized or promoted. Previous studies indicated that bureaucratic or administrative duties are preventing leading or learning to lead effectively. This is consistent with our findings and is regarded as a major hurdle and disincentive. The participants believe that opportunities to practice leadership were not available as most were struggling with week-to-week priorities. There are also major disincentive to take risks and lead. Though the research has indicated that the best way to develop leadership is to practice it, the opportunities were not available. All agreed that the lack of opportunities to practice while they learn is a major barrier for developing leadership capacity. This finding does suggest the value system in academia may have to be changed to get the "right" context. This may require evaluating and changing human resource, reward, and promotion policies. The participants seem to indicate their sensitivity to authority (organizational management, university structure, executive support). This is quite surprising since most of the participant came from non-bureaucratic organizations when compared to academia (perceived as highly hierachal and bureaucratic). Their perception is that practicing leadership within the academic context requires formalization of authority, with appropriate delegation and executive support. In addition, a formal structure for practicing leadership was also desirable. Most participants believe that practicing leadership in industry did not require formalization or structure but is a key requirement when practicing within an academic context. This
contradicts the pre-conception that academics desire academic freedom and risk-taking. Perhaps, this is a new reality that Australian universities are faced with in the stagnation of intellectual thoughts and innovation at the academic frontline. This contradicts findings at the management levels where perceptions are perhaps more "rosier" and optimistic. The findings do indicate that formalized professional development does play an important role in developing leadership skills, however, it must be "real-time" and have the opportunities to practice for it to be effective. All participants agreed that there is virtually no "space" for professional development, though there were opportunities for it. Most felt they were too pre-occupied with week-to-week priorities during semesters to be "bothered" about developing leadership capacity. All participants agreed that industry and life experience are important in developing leadership capacity, whether in the form of skills and/or traits. Some participants suggested that engineering academics can benefit significantly if they had some professional practice during or before their academic careers. Some participants suggested that the being in the "right" environment such as in professional practice in industry, does present excellent opportunities and the space to learn and practice leadership. This view is very much expected as most of the participants were practicing engineers. The non-engineers also perceived that industry experience is important in developing leadership skills based on their observations of their fellow engineering colleagues. Preliminary analysis was performed on the combined pre and post interview data coded based on Bayne & Constable (2009) leadership model. The data were coded into skills, characteristics (or traits), environment, context, and their relevant sub-nodes. The post-intervention interviews were collected after the participants experienced initially an "unsupportive" and later a "supportive" environment. The observation indicated that during the "unsupportive" sessions, participants were engaged with the briefing for the postgraduate program but were unable to translate that into group and individual activities (most participants went back to their day-to-day priorities and waited for someone to lead them). The workload buyout offered was perceived as "useless" or irrelevant as it will require further effort to recruit and train replacements for their existing academic duties. This designed environment was later changed to be more "supportive" with participants being prescribed with defined tasks and administrative support being added. The change had a positive effect and the group was actively engaged with the activities. The observation indicates that leadership vacuum alone within academia does not necessarily encourage exhibition of leadership even if opportunities were constructed. This is surprising considering that most of the academics have industry experience and engineering leaders in their own right, but chose not to exhibit leadership either as mentors or as leaders. The evidence indicates that authority and structures were perceived as important to operate within academia. It is quite evidenced that even if the environment is conducive to developing and exhibiting leadership, the context within academia presents inherent systemic barriers. One such barrier is that academics can operate within academia and be very successful without developing or exhibiting leadership capacity. One contentious suggestion is that there is a self-selection process for academics to enter academia rather than consider a practice-based career. Most importantly, providing opportunities and changing the discourse of academics will enhance leadership perceptions and behaviours; eg. Dedicating time for reflection such as the interviews and the engagement with EA, academics are more responsive to leadership
opportunities. One unexpected finding is that the survey instruments applied were also powerful tools for learning about and developing leadership capacity; ie. providing structured space and time for reflection on leadership. Supporting data were collected from other sources such as the engagement with EA (Figure 5-left) as well as a cross-faculty forum (Figure 5-right).

These were used to complement the interviews’ data. Industry-academic roundtable are more focused on the actual leadership attributes such as social awareness, communication skills, professional skills, relationships, and cultural intelligence rated highly. This is perhaps the strong belief that leadership can be learned, and not surprising that it is consistent with the interviews since most of the participants had a past existence in industry. Whereas the internal academic roundtable focused on the context (academia), environment (leadership structure and industry-university) and characteristics (vision and influence). This is an indication of the dominant drivers reside within the academic context and its operating environments as evidenced in our interviews. And perhaps it is this context and environment that have nullified the need for leadership skill development and instead rely very much on individual natural traits to influence outcomes, hence the academics’ focus on characteristics (traits).

**Conclusion**

This paper presented the preliminary analysis of data from semi-structured interviews and surveys with engineering academics based on an action-based participatory research into leadership at the faculty level. The findings in this paper align fairly consistently with previous empirical studies at the management level within an Australian university context. Frontline engineering academics perceived leadership as a behavior that can be learned but acknowledge that there are traits that can only be developed through life’s journey. Leadership is perceived not just as a competency, but rather a combination of nature (traits) and nurture (skills) that are governed by the context and environment at which the leadership is practiced; factors that straddle the interface between the
Academic (person) and University (organization). A distinctive finding is that academics are very sensitive to “authority”. This contradicts previous studies that suggest academics are not “governed” by authority, and exercise their academic freedom accordingly. Leadership opportunities should be appropriately formalized and delegated, with full and unambiguous executive, funding and administrative support, and exercise within an operating structure. Currently, there are major disincentives and hurdles for academics to take risks and lead. The findings also conclude that opportunities and space to practice leadership are important. Given that the prior research has suggested that academic leadership does impact on the quality of teaching, it would be advantageous for institutions to re-evaluate their context and value system. The findings presented are useful in providing an understanding of why academics do or do not pursue opportunities for developing and exhibiting leadership. The analysis is still ongoing and thus the assertions in this paper are loosely put forward. The evidence should provide clarity and support for assertions made as the analysis matures. Further work in analysis and data collection across faculties and institutions at a trans-national level are needed.

References


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"Knowledge Management" and Leadership in the Higher Education: A First Approach

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Abstract: Today, it is more and more important to develop competences in the learning process of the university students (that is to say, to acquire knowledge but also skills, abilities, attitudes and values). This is because professional practice requires that the future graduates design and market products, defend the interests of their clients, be introduced in the Administration or, even, in the Politics. Universities must form professionals that become social and opinion leaders, consultants, advisory, entrepreneurs and, in short, people with capacity to solve problems. This paper offers a tool to evaluate the application of the professor of different styles of management in the process of the student’s learning. Its main contribution consists on advancing toward the setting in practice of a model that overcomes the limitations of the traditional practices based on the masterful class, and that it has been applied in Portugal and Spain.

Introduction

In addition to technical and conceptual skills in students, the new academic curriculum at the University should include the development of different human skills, specifically those related to leadership skills. In the learning process, various researchers argue that the influence of the teacher and its effectiveness in the classroom depends, both on its style as the situational context in which it operates. For this reason, what constitutes effective leadership in a particular situation may be ineffective in others. Thus, it is essential designing a method for describing the teacher’s behaviour (that is, a code of conduct), and describing the relationship between different styles of leadership and performance in the learning process. This paper intends: 1) to build an active learning environment, in which students decide what and how to learn, and 2) to put into practice a didactic methodology based on active participation, motivation and interaction of students. There are various methods for describing the leadership style of the teachers. This paper is an incursion toward a model of good teaching practices, and is part of an international research, that was implanted at the postgraduate level at two universities, which for a long time apply didactic techniques based on competencies: the Institute of Visual Arts, Design and Marketing in Lisbon (Portugal) and Universidad Politécnica de Madrid (Spain). This research describes the process followed in this curricular design, vital to verify the effectiveness of this methodology and its intellectual dimension.
Literature review

Most of the studies on educational leadership suggest that there is not an ideal teacher, defined by certain characteristics of personality, or only by a way to act (there are very good teachers with personality traits and styles equally effective). Teaching models should focus on describing the manner in the teacher would be able to identify its style, recognize the responsibilities of their behaviour and describe the situations in which it makes sense a certain style of action.

Empirical research on this topic has been somewhat limited, mainly because of the lack of solid and tested models. Various studies seek to determine the leadership style of teaching, that is, transactional versus transformational style. However, scales on different styles of leadership are not universal, and have not practical utility. More research is required in postgraduate degree students.

Style of leadership

There are different theoretical approaches that have addressed the study of leadership in general, the most common being: the theories of the traits, characteristics and behavioral contingencies; and situational, transactional and transformational leadership (Bennetts, 2007; Pedraja et al., 2009). That is why some theoretical approaches and models do not share the same views and sometimes are contradictory (Elton, 2001; Lupano and Castro, 2008).

Many papers aim to find the style of leadership prevalent in teachers (Bass and Avolio, 2000; González and González, 2008), analyzing if the style is applied conforms to one transactional (professor exchanges qualifications and rewards for the effort of the students) or transformational style (teachers motivate, stimulate the students' analytical skills, and help them to achieve their objectives). Although a large part of the leadership literature highlights the importance of one of transformational nature (González and González, 2008; Muenjohn and Armstrong, 2008), various authors suggest that there is a need for greater knowledge of the type of leadership that is required in the current context, and they recommend refinement of the scales of leadership, developing simple procedures to facilitate decision-making in the classroom (Lowe et al., 1996; Mbawmbaw et al., 2006; Moss and Ritossa, 2007). This is because of the style of leadership is commonly measured in terms of multidimensional scales, such as that proposed by Bass and Avolio (1997). However, many researchers suggest various limitations of this type of scales: for example, that their factorial structure is not universal, some factors are further subdivided between itself, while others disappear. In addition, although many papers conclude that the transformational approach achieves a better performance of the professor, various studies refer to different styles of leadership, and they have no utility to act in an active way in the classroom. In this sense, this research seeks to shed some light on the relevance of a transformational leadership in the performance of the professor in the classroom.
Performance of the teacher

Various studies have proven that leadership has a significant impact on the performance in different business and areas. However, leadership in teaching process refers to the ability of the teacher to create a climate in the classroom that promotes learning, stimulating the satisfaction and the effectiveness of the students in their academic development (Antonakis et al., 2003). For this to happen, it is opportune to create in the classroom an experimental situation, in which the teacher tries to encourage the participation of students and their responsibility in the learning process (Caligiori and Diaz, 2006).

The importance of studying the climate generated in the classroom lies in the fact that a disinhibited environment reinforces orientation of students toward learning (González and González, 2008). However, various authors have shown that leadership does not influence on practices in companies for the students (Dochy et al., 1999; Joseph and Joseph, 1997; Pedraja et al., 2009). In general terms, the results obtained in various studies have shown that the same group can behave differently, depending on the teacher leadership that was exercised over them. In this context, it is very important defending participatory styles for reasons of motivation, satisfaction and effectiveness of learning process (Caligiore and Diaz, 2006). Although many studies on teaching methodologies are focused on identifying the aspects involved in the performance of students, increasingly there is a perceived need to integrate the leadership style of the professor with information about its performance; bear in mind the climate generated in the classroom, and generate performance protocols applicable in this area (Berggren et al., 2005). If we suppose that a participatory style of leadership reinforces learning of students, the performance of the teacher in the classroom provides information about what and how is this learning (AC Nielsen, 2000; Biggs and Tang, 2007). In Universities, it is very important to create a culture to learn in and through people, and for this there are two key milestones in the learning programme: the teamwork and the empowerment.

Research methodology

In this research we put into practice two modes of teaching, one of them to develop a participatory methodology in the classroom through work and panel presentations, for developing attitudes and skills of leadership. We tested different techniques on the participatory group: masterful class, debate, work and presentation in a group. In all cases, the students had to make their own decisions about the training content of the subject. Previously, professor investigated on expectations of the students. After the first items, developed by the teacher, students presented the topics by groups (two to three people). In the group of students on the one we applied non-participatory methods, methodologies were very traditional: professor established the objectives of the course, and he gave individual qualifications to students. To assess the results of these practices, we sent a questionnaire to the students, which included the following information: Part I: Leadership style of the teacher. Part II: Climate in the classroom. Part III: Degree of assimilation of the methodology. Part IV: Level of teaching performance. Part V: Identification data of the respondent. The variables in this research were collected in the
questionnaire with the scales and units of measure that are listed in the tables of results. For the preparation of the questionnaire we carried out a pretest with university professors and various external professionals, with knowledge and experience in this field. The field work in Portugal was held in the facilities of the University, between the June 28 and July 1, 2010. In Spain, information was obtained between the April 28 and June 1, 2011, and the sample included from undergraduate to postgraduate students. Table 1 provides details on this research.

Table 1: Methodological process of the research

<table>
<thead>
<tr>
<th>PHASE</th>
<th>ANALYSIS</th>
<th>METHODOLOGY</th>
<th>TECHNIQUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous</td>
<td>Documentary and validity of content analysis</td>
<td>Literature review</td>
<td>Bibliographic review</td>
</tr>
<tr>
<td>Identification</td>
<td>Reliability and construct validity</td>
<td>Quantitative research (analysis of overal reliability and initial factorial validity)</td>
<td>Exploratory analysis of the data</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Assessment of the variables</td>
<td>Quantitative research</td>
<td>Descriptive analysis of the data</td>
</tr>
</tbody>
</table>

Analysis of results

Table 2 shows, in comparative terms, the profile of the students who answered this questionnaire. As a whole, in this analysis it is worth noting the greater male presence among the students (54.8%), as well as the high proportion of students who work in private companies (83.5%).

Table 2: Sample (data in percentage, means and typical deviation).

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>STUDENTS</th>
<th>SPAIN</th>
<th>PORTUGAL</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE:</td>
<td></td>
<td>Mean</td>
<td>21.1 years old</td>
<td>25.1 years old</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T.D.</td>
<td>2.47</td>
<td>9.5</td>
</tr>
<tr>
<td>GENDER:</td>
<td></td>
<td>Male</td>
<td>74.6%</td>
<td>46%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>25.4%</td>
<td>54%</td>
</tr>
<tr>
<td>DOES HE/SHE WORK AT THE MOMENT?</td>
<td>Yes</td>
<td>14.3%</td>
<td>45%</td>
<td>68.7%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>85.7%</td>
<td>55%</td>
<td>31.3%</td>
</tr>
<tr>
<td>ORGANIZATION TYPE:</td>
<td>Public</td>
<td>12.5%</td>
<td>14%</td>
<td>16.5%</td>
</tr>
<tr>
<td></td>
<td>Private</td>
<td>87.5%</td>
<td>86%</td>
<td>83.5%</td>
</tr>
<tr>
<td>POSITION IN THE ORGANIZATION:</td>
<td>High</td>
<td>12.7%</td>
<td>27%</td>
<td>14.8%</td>
</tr>
<tr>
<td></td>
<td>Intermediate position</td>
<td>52%</td>
<td>8%</td>
<td>40.4%</td>
</tr>
<tr>
<td></td>
<td>Without main position</td>
<td>35.3%</td>
<td>65%</td>
<td>44.8%</td>
</tr>
<tr>
<td>EXPERIENCE IN THE CURRENT POSITION:</td>
<td>&lt; 1 year</td>
<td>33.3%</td>
<td>25%</td>
<td>15.3%</td>
</tr>
<tr>
<td></td>
<td>1 to 3 years</td>
<td>44.4%</td>
<td>36%</td>
<td>43.5%</td>
</tr>
<tr>
<td></td>
<td>&gt; 3 years</td>
<td>22.2%</td>
<td>39%</td>
<td>41.2%</td>
</tr>
<tr>
<td>TOTAL STUDENTS</td>
<td></td>
<td>63</td>
<td>58</td>
<td>121</td>
</tr>
</tbody>
</table>

Table 2 shows that Spaniard students have something more experience in the current position than Portuguese people, in Spain students occupy intermediate positions in their organization, so they are studying in order to promote themselves professionally. However, in Portugal students accumulate less experience than Spaniard students.
Measurement of the variables

This research started with the selection of variables representative of the areas identified as a frame of reference. The questionnaire was applied in Portugal on the total of the students, in order to avoid biases in the empirical structure, to validate the stability of the solutions obtained in each step and generalize the results beyond the sample obtained. This cross-validation allowed us to analyze data with two samples: one of them (in Spain) for the estimation, diagnosis and modification of the previous instrument of measurement; and the other (in Portugal) to cross-validate this analysis.

Evaluation of the variables

Table 3 presents the responses of the students at the scale of the leadership style of the professor. At this point it is interesting to note the high valuations averages of the participative style applied; in line with what is observed in other studies for this type of methodology (Pedraja et al., 2009). The detailed analysis of the table reveals high marks in the items: the professor "tolerates differences of opinion" (averages of 3.54 and 4.27), "different points of view" (3.79 on average in Portugal and 4.37 in Spain) and "generate new ideas in the classroom" (with values above 3.62 and 4.14, on a scale of importance of 1 -at least- 5 -maximum-). On the other hand, the items of motivation are the most valued by the students (the "enthusiasm of the teacher in the classroom" and "confidence in the accomplishment of the objectives", with average values of 4.26 and 4.64). The remaining indicators linked to the motivation of the professor, also they have averages exceeding 3 but with deviations more significant. In addition, the detailed analysis of the two groups of students reveals the fact that "the professor has a tendency to speak enthusiastically about the targets to be achieved".

Finally, empathy is a very appreciated by the students, because it reflects provision of the teacher with the student "in response to their feelings and needs" (2.97 average in Portugal, and 4.19 in Spain), and "... time to teach and guide" (4.13 and 4.57 averages). Something that was appreciated is also that "professor relates in a personal way with the student" (2.92 and 4.13 means), and "he treated me individually" (3.59 and 4.08).

Table 3. Items of style of leadership scale (data in percentage, means and typical deviation).

Table 4 presents the results of the evaluation of the performance of the teacher in the classroom. It is also noted that the empirical results in both cases are high for almost all
indicators collected in this research. In the first items, the views are consistent with the fact that the performance of teachers get "to improve the climate in the classroom with good humor" (3.69 and 4.81 on average) and that "the teacher uses teaching methods which I find satisfactory" (3.56 and 4.19). This analysis is in line with the results of previous studies, which emphasize the effectiveness of teaching methods in which students are co-producers of their own learning (Caligiore and Diaz, 2006, Moss and Ritossa, 2007).

With regard to the second group of questions, the items are related to aspects of extra effort on students, the values obtained have been more modest (averages between 3.28 and 4.18 in Portugal) than in the first set of data. In general, the students were satisfied with the way how they perceive the methodology, and its reflection in the results; but there are still some values of discordance and more significant in various items. Despite a significant number of neutral responses in the first 4 items, in a general way the students are in accordance with the performance of the teacher: "he implements ways to motivate and satisfy the needs of the group", "tasks to achieve the learning objectives", and the teacher is "ready to help them", so that, in general terms, the students feel happy with the teacher and the objectives of the course.

Table 4. Professor performance indicators (data in percentage, means and typical deviation).

In summary, it can be said that the students have a positive opinion on the issues in this research. It is very important to emphasize particularly the views of concordance, in the items "professor helps to analyze the problems according to different points of view", he "has a tendency to speak enthusiastically about the challenges to achieve", and "he treats each individual in a personal way". Thus, we conclude that results are in line with the development of attitudes, values and social skills, such as the new requirements of a dynamic labour market (AC Nielsen, 2000; UNESCO, 1998). The detailed analysis by groups of students reaffirms the findings summarized above. The high scores in undergraduate students relate to a large extent with the application of this technique in a smaller group of students, in classes converted into seminars and with its own methodology of cooperative learning.
Conclusions

The main contribution of this paper is to present some teaching techniques based on participatory styles of management in the classroom. In addition, this research presents an original scale of measurement of the leadership style of the teacher, and also the evaluation of their performance. Its purpose is that this instrument will be used as a tool for the academic improvement, and its justification is found in the growing interest in Europe for the quality in the Higher Education.

This research presents an exploratory scale ad hoc of the leadership style in teaching, which is very simple and operational, and it can be adapted by each teacher on the basis of teaching techniques implemented in their subject. Its virtue lies not only in the scope of this research, which has been carried out in two countries, and it has been discussed in students with academic and professional circumstances very similar; and too in contexts of participatory. In addition, these scales in this paper enable us to integrate the style applied by the teacher in the classroom with performance indicators, by modifying these in accordance with the levels and preferences of the students with each educational technique developed. This procedure is directly applicable in the classroom, and can also be taken in different countries. The knowledge of these practices is an essential tool for planning the academic curriculum of the students; and is of interest for directors of the educational institutions, as well as for academic managers and teachers, in order to analyze their own educational outcomes.

In this research we have evaluated the characteristics of the scales for measuring two concepts, both the leadership style of the professor, and the teaching performance. The implementation of this research in Portugal (for the identification of the model) and in Spain (for its subsequent validation) confirms the validity of the conceptual proposal presented in these pages. The innovative nature of this instrument lies to ask directly to students; unlike other approaches focusing on the evaluations of the teachers. Finally, although this tool has been applied exclusively in Information Technologies courses, does not exclude their extension to different levels of the educational system, as well as in other different areas of knowledge. In future research also will be of particular interest to the interaction of the leadership style of the professor with aspects such as the characteristics of the group that he guides.

References


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Teaching contextual knowledge in engineering education - Theory of Engineering Science and the Core Curriculum at the Technical University of Denmark

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Denmark

Abstract: Despite contextual knowledge is considered very important for engineers in performing their profession, experiences from decades in Europe and the USA have shown that teaching such topics in engineering education is challenging and often unsuccessful. One of the dilemmas is that social science based reflections related to the use and uptake of technology in society often conflicts with engineering students’ selfunderstanding and identity. Another dilemma is related to the specificity and modelling reductionism in engineering science compared to the complexity of problems in engineering practice. Consequently courses added into engineering curricula emphasizing contextual issues stay in stark contrast to the dominant instrumental disciplines of mathematics and techno-science content of core engineering courses.

Based on several years of teaching and experimenting with Theory of Science at the Technical University of Denmark, the paper argues that teaching contextual knowledge needs to overcome several barriers that tend to be neglected in engineering educations.

Introduction

Engineering and engineering education has throughout history been faced with challenges impacting not only the engineering practice but also the identity of engineers. In recent time, the dilemmas and challenges facing engineering practice and engineering education raise, according to Gibbons (1994), Christensen (2009), Downey (2006) and Williams (2002), a need for response strategies to:

- handle the societal problems related climate change, for example, how to handle environmental deterioration, increased populations and poverty.
- handle the increasing complexity of technologies which require responses not only to its impact on society but also to how to define and educate social responsible engineers
- handle ever increasing blurring boundaries between science and technology, also known as techno-science within new ‘fields’ such as biotechnology, nanotechnology etc. requires engineers to develop competences within cross-disciplines such as modeling, simulation and design.
- how to act as engineers in a hybrid world, where engineering is pulled ‘in different directions – toward science, toward the market, toward design, toward systems, towards socialization’ (Williams, 2002, p.70)
Professional as well as higher education in general produce communities of people with skills, insights and influence as specialists providing these groups with a monopoly of knowledge. This raises questions to their role as experts in constructing material and organizational structures and making decisions crucial for other groups in society and framing important aspects of working conditions and everyday life. The specialized knowledge that has become the core of most engineering educations with their emphasis on mathematics, techno-sciences has also contributed to the image of a self-contained professionalism difficult to understand and assess from other parties in society.

Demands put on engineers are a result of technology’s impact on society resulting in demands for these professionals to oversee and eventually foresee social impacts. The demands also relate to placing responsibilities in often complex situations of accidents and unexpected outcomes. As the demands and the responses are ambiguous the complexity in the division of influence and competences may render simple ideas of responsibility invalid. Consequently the interpretations of the challenges and the identification of the problems at stake do not result in simple and straightforward solution to how engineering education should respond to these challenges (Jamison, 2011).

Responses to context in engineering

The reactions and response strategies of the engineering institutions towards these challenges has been and are currently different in their scope. Since the 1960s humanities and social science, covering issues of creativity, cultural aspects of technologies, ethical considerations, political training and social engineering, have been part of the engineering institutions response strategies to educate engineers. But incorporating humanities and social science in engineering education has in many cases failed or created a disinterest among both engineering students and faculty members. Downey (2006, p.6) argue ‘Because of the dominance of images of engineering as technical work, especially technical problem solving, prior to this movement most engineering curricula demonstrated a relative disinterest in liberal education. Either it was fundamentally irrelevant to engineering education, as was often judged to be the case in Europe, or it was a necessary but peripheral contributor to ‘broadening’ the engineer as a person, as was often judged to be the case in the United States. Also, in the case of peripheral participation, faculty from the humanities and social sciences regularly experienced a tension between providing introductory experiences in the liberal arts, for which the concept of competencies was an inappropriate label, and serving the professional needs of engineers, e.g. by facilitating skills in communication’.

Other responses have been taking from the outset of engineering disciplines themselves adding discussions of social challenges and scientific problems to the already instrumental teaching and taking the outset in the problem solving strategies proposed in the technical disciplines. The need for including ‘real life’ experiences and problems have been an obvious response as these often transgress the boundaries of the technical disciplines themselves and render the challenges from the complexity of professional practices absolutely crucial.
The 'liberal arts' curriculum requirements in the US being part of the first years of engineering studies is a good example of an externalist response strategy based on the idea of educating learned citizens. The motivation taking the outset in creating a democratic, political culture bridging the vast differences in American society. This has some resemblance with the German idea of free universities providing a basis of 'Bildung' that comprise of a broad insight and an ability of critical thinking. While motivations might be different also France focused on including a broad education for their elite of state professionals including engineers. While the add-on disciplines from the humanities and social sciences have been institutionalized in the US, the European situation is much more diverse in how the demand for a broader knowledge base in engineering has been installed.

During the 1970s the critique of technology and its impacts on society resulted in more specific topics taken up at several technical universities including environmental issues, working environment, job degradation, business economy and use aspects of technology resulting in more specific courses taught based on sociology, psychology and economics but emphasizing these disciplines' take on technological development and its consequences. Though more specific and related to the engineering profession, the courses played more a role of 'social and green' add-on to the still dominant core of engineering courses. A specific approach has been taken by introducing ethics into engineering emphasizing the personal dimension of responsibility and how it is embedded in social structure. While the focus in sociology and economics tend to be on the societal institutions and their role in regulating technological development and implementation, the ethical framing tends to emphasize the individualized responsibility in engineering.

The EPICS (Engineering Projects in Community Service) programme founded at Purdue University in 1995 is an example if such an engagement taken from the theoretical realms into students practices within a 'community service learning' perspective by working with real life demands from community groups in a non-business perspective. This approach expose the students directly or indirectly to moral responsibility and ethical challenges at the same time as they learn to communicate with non professionals on goals for design tasks. The underlying assumption is that engineers 'do good' and seeks to meet the needs of civil society. In many ways the EPICS programme can be compared to the so-called Science Shops established in the Netherlands in 1970ties and spread mainly in European throughout the 1980ties and 1990ties (Brodersen, 2010). The idea of providing students with possibilities of real-life experiences as illustrated in the role of partnerships between student project teams and their partner organisation: 'During this phase, the project team learns about the mission, needs, and priorities of the project partner. A key aspect of this phase is identifying projects that satisfy three criteria: they are needed by the project partner, they require engineering design, and they are a reasonable match to the team's capabilities.' (Coyle et al., 2005, p.6). The dilemma is that the technological knowledge is not at stake, but present a set of background capabilities where the limits lie in whether they perform as a relevant design object and are in reach of the project team.

The EPICS programme is a response to the more general requests to engineering education coming from a.o. the ABET 2000 criteria demanding: 'In setting the goal for any
system they are asked to design, they will be expected to interact effectively with people of widely varying social and educational background. They will then be expected to work with people from many different disciplines to achieve these goals.’ (Coyle et al., 2005, p.1). Again in this phrasing, the problem of technology adaptation and relevance appear more or less unaddressed and the problem of making solutions useful for people is at large reduced to the ‘effectiveness’ interactions in identifying needs. Other similar examples can be found in student projects provided by for example Engineers Without Borders emphasising development projects with focus on technologies and engineers as core parts.

EPICS as well as Engineers Without Boarders illustrate a classic progressive perspective on engineering; where technology and engineering are perceived as a rather ‘neutral’ and professional entities that have to find their masters and ethical values offered from outside engineering knowledge. This produces a rather dominant, contemporary new heroic interpretation of engineering that can offer services to communities in parallel to serving international corporations and economic interests. It keeps engineering ‘clean’ and ‘unspoiled’ in its intrinsic values represented by the de-contextualised disciplines and the independence of engineering schools and educations. It also gives way to heroic strategies where ‘innovation and entrepreneurship’ can be interpreted broadly as innovations for society and mankind as well as several ways of performing as entrepreneurs.

These response strategies can be characterized as internalist strategies as the take the outset in the practices of engineering and how technology impacts societal actor groups. Engineering training is viewed as a specific, instrumental way to reduce the complexity of issues related to the use of technology as ways to order and improve social practices. This leads to several, different interpretations of the boundaries of the teaching and disciplines in engineering education. Engineering disciplines and their problem identification can be viewed as complete and the challenges are seen as a mere question of understanding the application context which brings the responses close to the add-on strategies of including new topics and disciplines outlined under the externalist approach. At the same time the disciplines and their framing and reduction of the problem space are crucial for understanding the challenges and the need for broader competencies encompassing communication skills and the ability to translate community needs into engineering problems.

Technology studies and the study of techno-science provide a useful social science inspired alternative knowledge base that addresses the specific questions of relevance for the practices of the engineering profession and thereby for broadening engineering education (Latour, 1988; Bijker, 1995; Downey, 2006). In this perspective engineering disciplines are not seen as complete, but rather limited in their scope. The integration of practical knowledge and problem identification in educational challenges the existing organization of course topics and disciplines in engineering programs, as many disciplines are very specialized within narrow fields of technology. This leads these disciplines to present solution spaces that in a broader perspective are superficial and very difficult to integrate in a meaningful way. Even though the integration seen in the perspective of
practicing engineers may be possible in e.g. project assignments, the core engineering disciplines dominate the curriculum and provides the students with an instrumental approach to engineering knowledge that guides the formation of their identity. This leads to response strategies that demand a revision of the content of technical subjects and courses to support design projects and to bridge between the needs of different actor groups and engineering education and the skills provided.

These different response strategies all open up for broader perspectives on engineering expected to improve the professional insights and competences of engineers, but what is considered important and taken up as the context that engineering is embedded in points in very different directions. These include differences in assessing the character and completeness technological solutions included in techno-science leading to different interpretations of the boundaries of core engineering and defining contextual knowledge and the context of engineering.

The scope of the paper

Throughout a period of several years of teaching contextual knowledge and more specifically a basic and mandatory course in ‘Engineering theory of science’ at the Technical University of Denmark (DTU), we have been faced with the challenge of having quite a large proportion of the students finding the course irrelevant compared to the core discipline courses they are taught during their bachelor education. Despite several improvements in the curriculum, the production of a specific textbook for the course and changes in the pedagogical approach, the criticism remains fundamentally unchanged. This has lead us to assume that other matters are at stake, than merely the students criticism of the pedagogy and content matters, but that their criticism instead reflects the course's position in the overall education and the role of contextual knowledge in relation to the engineering students' self-understanding and identity. Resulting in the scope of this paper being to analyze and discuss why contextual knowledge seems to challenge the engineering students and thus which barriers need to overcome for a successful integration of contextual knowledge in engineering education and curriculum.

The analysis is based on focus group interviews with students after finalizing the course, students' course evaluations from a period of 5 years, an evaluation carried out by Learning Lab DTU (Hussmann & May, 2009) and the analysis and suggestions for a future model of ‘Engineering theory of science’ based on the work of an interdisciplinary dialogue forum commissioned by the dean of bachelor educations at DTU in early 2011 that resulted in suggestions to integrate and anchor the course in clusters of disciplines at DTU and establish a cooperation between teachers from engineering disciplines and from technology studies (Jørgensen & Brodersen, 2011).

Theoretical framework

To understand the role of disciplines in education include an understanding of how these disciplines are framed within a scientific universe - whether this includes visions of objectivism and instrumentalism or perspectives of interpretation and history and site
specific conditions for understanding processes (Latour 1988; Cartwright, 1999). These are basic questions raised in the theory of science and in the study of scientific practices where the technical sciences are caught in the space between having a mathematical and natural science inspiration for objectivity and at the same time is dependent of the institutional and human actors’ engagement with the implementation and working of technology (Pickering, 1995; Bijker, 1995).

As important – seen from our experiences – is the role of identity formation among students influenced by the ‘hidden curriculum’ implied in the core courses of engineering education taught as mathematical and natural truth and given an instrumental flavour that support a rather reproductive and uncritical approach to knowledge. This implies questions of how this ‘engineering ethos or identity’ is created and sustained and which role it plays in students’ approach to learning. One of the important things that identity formation provides is an ability to select what can be considered to be relevant data and an ‘engineering problem’. Following this the dominant focus in engineering education on problem solving strategies with often only little emphasis on problem identification and the ‘wicked’ character of real life engineering problems also is expected to impact the building of an instrumental identity among engineering students asking for more of the same instead of asking critical questions to their own knowledge base (Downey, 2006; Newberry, 2007).

**Findings**

The course analyzed is the ‘Engineering theory of science’ course at DTU (in Danish: Ingeniørfagets Videnskabsteori). The purpose of the course is to enable the students to understand and evaluate:

- the relationship between scientific knowledge and practical experience in creating new technologies,
- the types of knowledge and skills needed in engineering work, and
- technology’s properties, its historical dependency and meanings in a societal context.

The course is structured in three themes: ‘Technology and Development’, ‘Engineering work and competence’, and ‘Theory of engineering science’. In the first, theoretical part the students learn to see engineering practice as a field of competences that combine theory, empirical data and models, as well as experience-based heuristics for solving problems in various technological domains including the social and environmental challenges that adds complexity to the specific problem space of the domain. In the second, project part of the course the students analyze selected problems in one or more technology domains relevant for their engineering discipline. The students are encouraged to identify problems for their projects taking the outset in the technology domains relevant to their engineering program. The course material is presented in a textbook (Jørgensen, 2009).

One of the most crucial conditions for the course so far has been set by DTU as it is mandatory for all engineering bachelors programs and has to be provided in a generic
fashion which implies that approx. 250 students follow the course every semester and the teaching has to be organized as a combination of lectures held by senior faculty and class and group supervision carried out by student instructors trained in a special series of seminars to deepen their knowledge of the course topics.

In 2009 the teachers of the course asked the pedagogical unit at DTU to perform an independent evaluation of the course. This was triggered by a situation where several improvements in the textbook material, in the cases used in the class teaching and in the lectures improving the engagement of student turned out not to change the students assessment of course though it clearly improved the quality of the student project reports and showed that there was almost no correlation between the students assessment of course and the quality of the reports seen as a measure of their learning during the course. Prior to the evaluation, several focus group interviews with students following the course were carried out by the team of teachers, to explore why the students felt this resistant towards the course. One explanation launched by the students was, that it was not the course in itself, but rather the fact that the course was mandatory and in some ways challenged their core disciplines (Brodersen, 2008).

Some of Learning Lab's conclusions from the evaluation (Hussmann & May, 2009, p.1-3) were:

1. Experiences from other Danish university in teaching the course theory of science show the same problems as at DTU. Thus it seems to be a general challenges to make the course relevant to the students as well as to ensure a successful integration of the course.

2. It is the ambition that the students learn to analyze and discuss various theoretical concepts and theories. This may be impossible within a 5-point course with approaches from human and social sciences that seems so different from what engineering students are accustomed to.

3. One of the major contextual problems for the course and its placement at DTU is the lack of integration between the course and the bachelor programmes. The possible synergy effects are not utilized, and the course is consequently seen as an appendix to the core courses.

4. It is clear that students’ attitude toward the course is affected by older students and advisors.

The dean followed up on the evaluation with the following statement: 'In 2008, due to critical CampusNet evaluations, the teachers responsible for the course requested LearningLab DTU to conduct an evaluation of the course 42610 Engineering Theory of science (IFVT). The evaluation resulted in a general recognition of the course content, format but it also pointed out some aspects of improvements. These improvements are implemented, however it is clear that many students still have difficulty in accepting the course's relevance, and the course does not match their picture of what is relevant knowledge for engineer.' (Vigild, 2011)

Resulting in a dialogue forum: 'In order to create a greater coherence between the contents of the course 42610 ‘Engineering theory of science’ and other engineering subjects at
undergraduate education and to improve the students’ perceptions of the course, a group is set up with the objective of - through dialogue - to develop proposals to replace the current generic training concept with a solution that to a higher extent integrates the course in the undergraduate programs.’ (Vigild, 2011)

The dialogue forum found that a major challenge for the teaching of contextual knowledge, very difficult to change, is that students perceive ‘real’ knowledge as something that can be expressed in mathematics and formulas contrasted by the open ended problems raised in the course. This despite the fact that the course is filled with guiding methods, that almost makes its approach appear instrumental and not particularly loose and discursive.

Concerning the possibility of handing the course over to the specialized departments, the conclusion was clear, as the group assessed that the different technical departments’ specialization would make it very difficult to maintain a holistic perspective and the skills needed to maintain the course at a reasonable level. The obvious risk is that societal aspects and the theory of techno-science soon will be lost due to ‘local’ department interests in expanding their own teaching, as is has happened in most of the introductory courses established at DTU to introduce students to ‘engineering work practices’.

One of the big challenges is the size of a generic course that gives little opportunity for the teachers to provide examples that are relevant to all students. A conclusion was that the size of the course itself gave the students the impression that this course had low priority and compared to the mathematics courses teaching contextual knowledge differs dramatically as the course is expected to address the students own problems and questions while mathematics introduces an abstract knowledge that provides an impression of not needing a context of use.

The dialogue forum therefore sustained the conclusions of the dean by stating that a reform cannot be achieved by making minor changes within the already existing framework. It is the curriculum premise of the course that is wrong, including the idea that this is a generic topic that can be taught with a minimum of resources.

**Recommendations**

The proposal from the dialogue forum concluded that the main challenges for the teaching of a course in ‘Engineering theory of science’ is grounded in the relations to other core engineering courses and the implicit and explicit identity formation of engineering students.

To overcome these barriers for teaching contextual knowledge a co-called ‘hybrid’ model was outlined as an experiment to foster motivation and commitment among the students (Jørgensen & Brodersen, 2011). Where the course presently is implemented as a common generic course for all undergraduate programs, the revised ‘hybrid’ model will be tailored to groups - clusters – of undergraduate programs with similarities in their practice domains and disciplines and by the involvement of a combination of teachers with an interdisciplinary knowledge of socio-technical analysis / science and teachers with specialized knowledge in specific undergraduate programs.
An important supportive element of the proposed hybrid model of the course is to establish an academic center for ‘engineering domain science’ inspired by a model that MIT has used about systems theory across different applications. The idea here is that teachers meet to seminars organized around different academic themes that can be mutually inspiring and lead to research publications across the academic divisions. The professional networks can also play a role in the training of scientific staff at DTU.

The hybrid model requires the involvement of the bachelor program teachers in planning and implementing the course. It is not possible exactly to specify how extensive the cooperation in practice should be, as it still is the idea that the primary completion of the course is run by teachers with an interdisciplinary knowledge of the main themes included in course.

The case discussed in this paper, demonstrates the need to overcome some of the disciplinary disintegration that has developed in engineering education and to avoid – at least partially – the role of contextual teaching and learning to end up as marginal, add-on courses and disciplines that stay in contrast to ‘hidden’ curriculum supporting an instrumental view of competences among students and supporting a rather technocratic identity building. Further studies of the identity building and its impact on engineering problem framing and problem solving strategies will also support the improvement of the teaching of contextual knowledge in an integrated fashion.

**References**


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Session 4: Thursday morning

**Topic: Curricula 1 – Chair: Amparo Camacho**

*Assessment as a tool for improving the education of engineers: experiences of international accreditation of the Universidad del Norte.*

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**Abstract**: One of the biggest challenges in contemporary education is related to the evaluation of the education process, and particularly at college level becomes a challenge if taking into account the characteristics of students entering this level, the characteristics of modern society, and the demands that society makes to the college on the profile of the engineer that is being required.

The Engineering College of the Universidad del Norte, obtained in 2010 the international accreditation granted by the agency ABET. In a similar way the six programs of the College are accredited by the colombian agency on accreditation of high quality. One aspect that has largely contributed to obtaining accreditation of the programs has been having a model of quality assurance, whose core is the Assessment process, which is based on ABET EC2000.

The model developed in the College of Engineering has become a national benchmark for various engineering schools.

**Introduction**

Universities face today big challenges in terms of rapidly changing societies, particularly on aspects that directly or indirectly relate to the professional exercise of engineers; this reality is requiring the colleges of engineering to guarantee to today’s society, a qualified professional performance of its graduates. To adequately respond to social, economic, environmental and technological demands among others, engineering colleges require the development of high standards training programs and implementation of quality assurance mechanisms. The College of Engineering at Universidad del Norte, consisting of six engineering programs, has implemented a quality assurance system for the education
of their students, which has allowed through the ongoing review of its education processes and the progress evaluation in achieving educational objectives and skills development as defined in the profile of graduates, to improve curricular aspects, as well as teaching, learning and assessment processes to positively impact the development of skills in college graduates.

This paper will present the education process implemented by the college for each of the six programs that comprise it, focusing the presentation in the assessment processes developed, their features, the results derived from their development, especially those obtained by progressive improvement cycle; likewise, the paper includes the actions that are being implemented today as a result of the recommendations obtained in the process of international accreditation.

Framework

Due to the constant and rapid development the world is going through today in multiple productive sectors, a reflection of globalization, every day requires better trained professionals with better university education, which is why universities are increasing efforts to offer quality programs which meet the needs of society and industry in general.

One of the main objectives of the Engineering College of the Universidad del Norte is providing quality education. Quality in higher education includes aspects such as formulation of learning objectives relevant to professional performance and teaching-learning processes that guarantee their acquisition, and knowledge by teachers in the learning styles of their students, to know how to assist them in achieving their objectives (Sparkes, J, 1995). As such, the assurance of quality is used to improve teaching and learning processes (Al-Qutayri & Shubair, 2009).

To obtain a system of quality assurance, academic resources are needed, as well as infrastructure, management and training of university faculty, where should be a total commitment of both these and the directives of the institution. This commitment is vital because the importance of developing strategies to strengthen the growth and development of the institution through the quality assurance is spread throughout the university community. Once done, the model to be used should be designed to achieve the objectives, that’s why a self-study analyzing the current state of the process has to be done, in order to identify those points that must be addressed through strategies and actions to be taken. After this, a pilot test in which the implementation strategies are done and actions listed above is carried out, and thus it is evaluated whether the results meet the objectives intended. Once the pilot test is finished, final corrective actions are taken, and the results are again compared with the goals. If a positive result is obtained, the system design process ends; otherwise, the most important points that should be improved are identified (Camacho & Ruiz, 2010).

The previous system was implemented, based on guidelines established by ABET under the EC2000 (Engineering Criteria 2000) and it essentially consists on the objective measurement of student performance and at the same time, to identify those aspects that should be improved in the formative process. The EC2000 formulated by ABET, focuses on
the establishment, evaluation and adjustment/redefinition of mechanisms for achieving the learning objectives and developing the competences of the professional engineer in the context of contemporary society.

This system consists of several components that have a significant influence on the development. One of them is the Curriculum Modernization Project (PMC), formulated by our university, which allows continuous updating of the curriculum of programs, taking into account national and international benchmarks for the education of engineers and the needs of society, thus allowing students to have a process of comprehensive education and skills development required by the global market, and social and personal development.

Likewise, the assessment process has become the core of the quality assurance system implemented in our College of Engineering and can be understood as follows: "Assessment is the process of measuring the performance, work product or a learning skill and giving feedback, which documents growth and provides future directives to improve future performance" (Parker, Fleming, Beyerlein, Apple, & Krumsieg, 2001). Among the variables that are worth highlighting because of the impact for the assessment, the included are: the levels of knowledge and skill of the teacher regarding the assessment and the expertise of the latter in what is being taught and assessed, the time available for preparation of the assessment design, the degree of trust that exists between student and teacher, and finally the capacity for improvement through analysis of information obtained (Parker, Fleming, Beyerlein, Apple, & Krumsieg, 2001).

Within this framework, the College of Engineering at the Universidad del Norte has designed and implemented its system of quality assurance of education, based on the EC2000 and developing the Assessment as the backbone of the system, reason for which it has been called "Global Assessment Model".

**Global Assessment Model**

**Background**

"Quality assessment is defined as the external review of, and judgments about, the quality of teaching and learning in institutions." (Heywood, 1995)

Within the management done for obtaining the system for continuous improvement, the use of assessment at the College of Engineering has been implemented since 2005; however, in previous years, actions were carried out that were necessary to achieve this end.

Thanks to this, it was possible to obtain international accreditation ABET. The following is the timeline outlined for the process.
Description

The global assessment model consists of key elements that make it yield the desired results early in the system of quality assurance. The courses outcomes, program outcomes and program educational objectives, which will be described below, are the base components of the model, where the measurement and analysis of the results of these, make the quality of education offered in college engineering very high, being recognized nationally and internationally, increasingly positioning itself as an institution that provides the best human resources, highly educated in each market need.
The model is directed to measuring education not only academic student’s education but also the professional formation, making it more competitive in the world of business. "This is especially true as industry views an increasingly larger portion of the science and engineering labor pool more like a commodity then a profession" (Shuman, Besterfield-Sacre, & McGourty, 2005).

The assessment of the “Courses Outcomes” (CO) is the first process that takes place in the model and is carried out every six months. It is a process formulated and developed as a mechanism to support and monitor the process of curriculum modernization planned out in 2005, which initiated its development progressively; in 2008, after 3 years, the complete assessment model was developed and from then it has been used in all engineering programs. The main objective of the assessment of CO is to measure student outcomes obtained in the qualifying evaluations and activities designed for this and comparing them with the learning objectives set by the college of engineering. This will identify those weaknesses presented by the students in order to design better strategies to help improve performance in the subject. The strategies are to be implemented in the following period, and they will be analyzed, measured and evaluated at the end of it; this stage is called "loop closure". The latter is displayed and easily identified in the closing report made for each course called "Final Course Assessment Report" (FCAR) (Camacho & Ruiz, 2010).

The second process takes place is the Assessment of the "Program Outcomes" (PO), which is done annually. It applies for all program outcomes formulated under the scheme EC2000 by ABET. Similar to the CO, in the assessment of the PO, measurement, evaluation and improvement processes are carried out (Camacho & Ruiz, 2010). As such, it should use tools to measure from different aspects the performance of students in their programs. The tools currently used are:

- **Evaluation "SABER PRO"**: This is a state examan conducted annually and regulated by the Colombian Ministry of National Education; its objective is to check the skill level of students about to graduate (ICFES Instituto Colombiano para Evaluación de la Educacion Superior).
- **Report of the National Accreditation Commission (CNA)**: A report where it is determined whether the engineering programs meet national standards; the frequency of reporting is determined by CNA.
- **Comprehensive Exam (CE) 1 and 2**: These institutional tests are administered since 2008, and performed 2 times per semester. The CE1 seeks to measure the knowledge of students who have completed the basic training cycle (Mathematics, Physics, Chemistry and Reading Comprehension). Likewise, the CE2 is applied to students coming to the end of their education process where professional skills and knowledge are evaluated.
- **Measurement of performance in professional practice**: Although internships are not mandatory in the school of engineering, many students carry them out as an option. The company provides semester evaluation of student performance in practice.
- **Surveys of graduates**: Performed semi-annually to students who finished the entire curriculum and are close to graduating.

The assessment of Program Educational Objectives (PEO) is held every 3 years and is the main objective of measuring the professional performance of the engineering school graduates. As in previous cases, the process comprehends measurement, evaluation and improvement. The two tools used to achieve this goal are:

- Surveys of employers: The impact of professional exercise of graduates in the business sector is analyzed.
- Surveys of graduates: The satisfaction of graduates in the local and global market, as well as achievements taking into account the program objectives is inquired.

**Results**

The Global Assessment model has been evolving, so that today, one can consider that there is a proven model in progress in terms of cycles of improvement and is sustainable. This is one of the most important results of maintaining a system for quality assurance in the education of students, which continuously evaluates the objectives and uses the results to improve the programs (Sarin, 2000).

Based on the recommendations made by program evaluators of ABET, best practices schemes were designed and are being implemented, which are making it possible to achieve a significant level of improvement with regard to the functioning of the global model and obtaining results for decision making. Among the tools being used in the improved model, the rubrics for assessment of the program outcomes of the programs are highlighted. The use of rubrics was started first in 2010 in the semester as a pilot with two programs: Mechanical Engineering and Systems Engineering program.

Since the objective was to measure the achievement of program outcomes to establish the improvement cycles and provide formative feedback, it was decided to use analytic scoring rubrics (Mertler, 2001).

Previous to the use of rubrics, the evaluation cycle for the program outcomes was redefined in order to simplify the process of collecting, organizing and processing the data, thus focusing on a more accurate assessment of program outcomes.

The redesign of the process allowed for a better assessment of program outcomes, based on rubrics, provided the faculty the assessment of the courses and promoted innovation in teaching and especially in the methods of evaluation; today there is a better focused analysis, which has permitted the implementation of improvement actions that are positively impacting the processes of education of students.

**Future work**

From the results obtained from the pilot developed, the global assessment model has been redefined.
In 2011, the standardization process, through process redesign, of the periodicity of the assessment and the tools used to it began. All engineering programs, to date, are implementing the redesigned model and using rubrics for assessment of program outcomes.

The periodicity of the assessment of program outcomes, will be conducted in a manner that concentrates efforts on a more focused and precise assessment; in the previous model, every program outcome of each academic program each semester was evaluated twice a year, but from now they will be evaluated over a period of one year, so that in each semester half will be assessed and in the following academic semester it will be completed. Based on the rubrics that were established, every program outcome is assessed in the selected courses using outcome-specific assignments or tasks (Universidad del Norte. Department of Mechanical, 2011); the main instruments for gathering information such as surveys, interviews, and focus group are being prioritized and redesigned, and courses for faculty training in modern methods of evaluation are being designed.

It is expected with the above actions to bring the system of quality assurance in education at a level of optimization and self-regulation that ensures sustainability over time.

References


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Quality assurance in engineering education in Russia

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Abstract: According to the Federal Law, accreditation in Russia exists at two levels, state (run by a governmental organization) and professional (run by public professional organizations). The Federal Education and Science Supervision Service (Rosobrnadzor) is the governmental organization that is responsible for state quality assurance in education. The state quality assurance system is an assessment of HEI based on a comprehensive analysis of HEI resources and activities. It includes licensing and state accreditation. State accreditation is institutional. Professional accreditation focuses on the assessment of the content and quality of particular HEI's educational programmes. The Russian Association for Engineering Education (RAEE) is responsible for professional accreditation of educational programmes in engineering and technology. In 2009, the RAEE modified the criteria for accreditation of engineering programmes taking into account the new Federal Educational Standards and considering the membership in international organisations (Washington Accord and ENAEE). The new RAEE criteria are discussed.

Introduction

Issues related to higher education quality assurance became crucial in Russia in 1990’s, when HEIs were given more flexibility in curriculum design and the number of HEIs and programmes began to increase. In order to ensure the quality of higher education, a procedure of accreditation was implemented through the Federal Law “On Education”. According to the Law, accreditation in Russia exists at two levels, state (run by a governmental organization) and professional (run by public professional organizations). Normally, state accreditation is institutional while professional accreditation deals with educational programmes.

The state quality assurance system is an assessment of HEI based on a comprehensive analysis of HEI resources and activities. It includes licensing and state accreditation. For the time being the Federal Education and Science Supervision Service (Rosobrnadzor) is the governmental organization that is responsible for state quality assurance in education in Russia. In 2001, Russian Accreditation Agency (Rosaccredagentstvo) of Rosobrnadzor got a status of INQAAHE member and in 2006 of ENQA provisional member.
Licensing is an identification of the facilities, financial support and resources including information ones of educational institutions to meet the state requirements. The aim of licensing is to establish the right of HEI to deliver educational services. State accreditation is the establishment of equivalency between the content, level, and quality of the education offered and the requirements set by the State Educational Standards. The state accreditation grants to the HEI the right of awarding state degrees and issuing state standard documents of higher education. State accreditation establishes the status of higher educational institution. For the time being new criteria for the state accreditation of the new Federal and National research universities are being developed.

Professional accreditation focuses on the assessment of the content and quality of particular HEI's educational programmes. In accordance with the Federal Law “On Education”, professional accreditation is the responsibility of public professional organizations. The Russian Association for Engineering Education (RAEE) is responsible for professional accreditation of educational programmes in engineering and technology.

The RAEE Accreditation Centre was established in 2002. In 2004, the Agreement between the Federal Education and Science Supervision Service and the RAEE was signed. The Parties agreed to integration aimed at improving the quality of engineering education for the Russian economy due to updating and developing the national systems of professional accreditation of HEI’s educational programmes.

From 2003 to 2011 more than 160 engineering programmes in Russian Technical Universities were accredited by the RAEE Accreditation Centre. The list of accredited programmes is available on the RAEE web-site: http://www.ac-raee.ru/eng/reestr.php and on the ENAEE web-site: www.enaee.eu/eur-ace/eur-ace_accredited_programs.htm.

The RAEE Criteria for Engineering Programmes Accreditation

The system of higher education in Russia, which joined the Bologna Process in 2003, has been undergoing transformations for more than 20 years. At present, Russia is entering a new stage of higher education system modernisation caused by development and introduction of the new Federal Educational Standards of the third generation and mass transition to two-cycle system of higher education: First Cycle Degree (FCD) - Bachelor (4 years) and Second Cycle Degree (SCD) - Master (2 years). This system still includes 5-year educational programmes of Specialists’ training (integrated programmes leading to SCD) in a number of fields. Thus, there are likely to be considerable changes in Russian system of engineering education, i.e. reduction of the study period at the university by one year (transition from 5-year Specialists’ programmes of to 4-year Bachelors’ programmes in majority of fields), which is being the subject of many debates.

The RAEE cooperates with Russian Government, HEIs and industry in developing criteria for professional accreditation of engineering programmes corresponding to lines of modernization of higher education system. At the national scale the RAEE principal aim is to enhance the quality of programmes in engineering and technology through their external evaluation. At the global scale the RAEE strives for international recognition of the accredited programmes and graduates qualifications (Chuchalin et al, 2008).
Since 2004, the RAEE has actively participated in the elaboration of the common European system for accrediting engineering programmes set within the EUR-ACE (EUropean-ACcredited Engineer) framework supported by the European Commission. In 2006, the European Network for Accreditation of Engineering Education (ENAEE) was founded, and the RAEE became a founding member. For the time being the RAEE is authorised to award the EUR-ACE Label to accredited First and Second Cycle Degree engineering programmes in Russian HEIs. In 2007, the RAEE got a status of provisional member in the Washington Accord (Chuchalin et al, 2009).

In 2009, the RAEE modified the criteria for accreditation of engineering programmes taking into account the new Federal Educational Standards and considering the membership in international organisations (Washington Accord and ENAEE) (Chuchalin et al, 2010). The RAEE activities have been approved and supported both by the Russian Ministry of Education and Science and by professional organizations, such as Chamber of Commerce and Industry of the Russian Federation, Union of Employers and Businessmen, etc.

Given priority to significance of engineering profession, role of professional community in engineering programmes evaluation and international engineering agreements, the RAEE initiated the revision of the existed system of professional accreditation in order to make it consistent with those of the world leading engineering organisations. These changes resulted in elaboration of the new set of the working documentation (the outcomes-based criteria and accreditation procedure, self-study manuals, expert guidelines) compatible with that existing in the Washington Accord signatories and ENAEE members – the world leading organisations in accreditation of programmes in engineering and technology. The revision was encouraged by the leading Russian universities that actively participated in elaboration of the new approaches in quality assurance.

For the time being the RAEE accreditation criteria are grouped as follows:

1. Programme objectives
2. Programme content
3. Students and study process
4. Faculty
5. Professional qualification
6. Facilities
7. Information infrastructures
8. Finance and management
9. Graduate

The RAEE significantly modified Criterion 5 (Professional qualification) for accreditation of FCD and SCD engineering programmes. The new RAEE Criterion 5 for two-cycle engineering programmes professional accreditation is based on the fact that in up-to-date postindustrial society engineering activity acquires increasingly integrated, complex and innovative character. Engineer equipped with methodological knowledge, unlimited information resource (the Internet) and cutting-edge computer systems is able to solve research, project, design and other complex technological problems. Complex engineering activity is compound and multicomponent. It embraces wide range of various technological issues. Project decisions are based on fundamental principles with usage of...
modeling and optimisation. It is supposed that a Bachelor (a graduate of the FCD engineering programme) should be prepared for complex engineering activity.

**Innovative engineering activity** is aimed at development and construction of new technology, designed as a commercial product providing social and economic effect and therefore marketable and competitive. Innovative engineering activity is multilevel and interdisciplinary, based on fundamental and applied knowledge. It requires deep analysis and design of sophisticated models. It is supposed that both a Master and a Specialist (the graduates of the SCD engineering programmes) should be prepared for innovative engineering activity.

Characteristics of complex and innovative engineering problems that serve as a basis to form the RAEE requirements to a Bachelor, a Master and a Specialist competences are given below:

<table>
<thead>
<tr>
<th>Complex Engineering Problem</th>
<th>Innovative Engineering Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>embraces wide range of various technological issues,</td>
<td>is specialized and assumes deep analysis of engineering and other issues,</td>
</tr>
<tr>
<td>does not have an obvious decision, requires abstract thinking, original analysis and construction of according models,</td>
<td>does not have an unequivocal decision, requires deep analysis and design of sophisticated models,</td>
</tr>
<tr>
<td>requires knowledge enabling to use an analytic approach based on fundamental principles,</td>
<td>requires interdisciplinary basis and combination of deep fundamental and applied knowledge and its usage in “unexpected manner”,</td>
</tr>
<tr>
<td>includes uncommon tasks beyond the standard decisions,</td>
<td>as a rule includes uncommon tasks beyond the standard decisions,</td>
</tr>
<tr>
<td>embraces various groups of stakeholders with wide range of requirements, controversial among them,</td>
<td>is usually focused on target group of stakeholders,</td>
</tr>
<tr>
<td>has significant contextual consequences,</td>
<td>has critical contextual consequences,</td>
</tr>
<tr>
<td>is compound and multicomponent.</td>
<td>is complex and multilevel.</td>
</tr>
</tbody>
</table>

**Solution of Complex Engineering Problems**

The characteristic "wide range of various technological issues" contained in the definition of "Complex Engineering Problem" refers to the complex engineering tasks from different areas of knowledge. The characteristic "does not have an obvious decision, requires abstract thinking, original analysis and construction of according models" means that to solve a complex engineering problem a Bachelor uses the methods of modeling, mostly mathematical, based on interpreting an information about a real object to mathematical symbols and operating them (solving an equation) to solve the problem.

The characteristic "requires knowledge enabling to use an analytic approach based on fundamental principles" means that analysis of the processes in a technical object should be accomplished by a Bachelor using the principles of physics explaining its functional concept.

The characteristic "includes uncommon tasks beyond the standard decisions" refers to engineering tasks that are not typical and there are no standard procedures to solve it. For example, a Bachelor designs technical object and its operating system in conditions of
unavailability of standard components with the required parameters and characteristics. In this case a Bachelor should solve the task with choice and usage of nonstandard components applying it in the most optimal manner.

The characteristic "embraces various groups of stakeholders with wide range of requirements, controversial among them" refers to the objects of engineering activity in sphere of technology, as a rule, of general application, that are consumed by various branches of industry. The characteristic "has significant contextual consequences" means that solving a complex engineering problem influences not only technology, but related economics, ecology and social area as well.

The characteristic "is compound and multicomponent" is connected to the existence of factors influencing the solution of the complex engineering problem. For instance, new technical object is created by a Bachelor in accordance with the technical enquiry, containing the requirements to its basic characteristics with the whole range of limitations.

**Solution of Innovative Engineering Problems**

The notion "specialized" refers to the problem of the relatively narrow sphere of knowledge. The notion “does not have an unequivocal decision, requires deep analysis and design of sophisticated models” means that to solve innovative engineering problem both a Master and a Specialist uses the methods of optimisation and mathematical models on the basis of differential or integral equations systems to find out the best possible decision.

The notion "requires interdisciplinary basis and combination of deep fundamental and applied knowledge and its usage in "unexpected manner" means, for example, that a technical object of a new type is created by Master or Specialist due to the application of innovations in design (mechanics), operating scheme (electrical engineering, electronics), application of new materials (material science), etc., combination of which provides synergetic effect. As a rule, both a Master and a Specialist deal with non-typical problems when designing new technical objects and new components.

The notion “is usually focused on target group of stakeholders” concerns innovative engineering activities of both a Master and a Specialist when designing technical objects of a new type including special ones, developed for application in certain technical devices and technological installations for the customers in particular branches of industry. The notion “has critical contextual consequences” means that the solution to the innovative engineering problem improves methods and technologies qualitatively, changing their essence, and related economy, ecology, social life, etc.

The notion "multilevel" refers to innovative engineering problems which are solved on the basis of various levels problem solution. For example, a technical object of a new type can be designed by both a Master and a Specialist due to the application of new materials preserving the design, scheme, and so on. All this requires the solution to the sophisticated problems of the material science (complex mathematical models and physical experiments)
and some other issues that are to be solved at lower levels (empirical calculations, simple experiments, etc.).

Characteristics and notions of complex and innovative engineering problems can be observed and explained in a great number of ways. However, the above notions give general overview about the main differences in the description of engineering activity when it comes to decision making and problem solution. All this defines diverse requirements to the level of competencies of those who should solve such problems. The RAEE requirements set for the Bachelor, Master and Specialist competencies in the area of engineering and technologies are shown below.

<table>
<thead>
<tr>
<th>FCD (Bachelor)</th>
<th>SCD (Master, Specialist)</th>
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</thead>
<tbody>
<tr>
<td>1. Professional competences</td>
<td></td>
</tr>
<tr>
<td>1.1. Fundamental Knowledge</td>
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</tr>
<tr>
<td>Apply comprehensive knowledge of mathematics, natural and social sciences, economics and engineering in the interdisciplinary context of complex engineering activities.</td>
<td>Apply in-depth knowledge of mathematics, natural and social sciences, economics and engineering in the interdisciplinary context of innovative engineering activities.</td>
</tr>
<tr>
<td>1.2. Engineering analysis</td>
<td></td>
</tr>
<tr>
<td>Identify and solve the problems of complex engineering analysis applying comprehensive knowledge and modern analytical methods and models.</td>
<td>Identify and solve the problems of innovative engineering analysis in the conditions of uncertainty applying in-depth knowledge, analytical methods and complex methods.</td>
</tr>
<tr>
<td>1.3. Engineering Design</td>
<td></td>
</tr>
<tr>
<td>Design solutions for complex engineering problems applying comprehensive knowledge and methods to achieve the optimal results to meet defined and specified requirements.</td>
<td>Design solutions for innovative engineering problems applying in-depth knowledge and original methods to achieve the advanced results in the conditions of uncertainty.</td>
</tr>
<tr>
<td>1.4. Investigation</td>
<td></td>
</tr>
<tr>
<td>Conduct investigations of complex engineering problems including information search, experiment, and data interpretation applying comprehensive knowledge and modern methods to achieve required results.</td>
<td>Conduct investigations of innovative engineering problems in the conditions of uncertainty including critical analysis of data, complex experiment, interpretation and decision making applying in-depth knowledge, original methods to achieve required results.</td>
</tr>
<tr>
<td>1.5. Engineering Practice</td>
<td></td>
</tr>
<tr>
<td>Select and use appropriate resources, equipment and tools for complex engineering practice taking into account economical, environmental, societal aspects and other limitations.</td>
<td>Create and use appropriate resources, equipment and tools for innovative engineering practice taking into account economical, environmental, societal aspects and other limitations.</td>
</tr>
</tbody>
</table>
1.6. Specialization and labour market orientation

| Be prepared to invest knowledge, skills, time and effort for complex engineering activities as required by potential employers and follow their corporate culture. | Be prepared to invest knowledge, skills, time and effort for innovative engineering activities at enterprises and companies that are potential employers and follow their corporate culture. |

2. Transferable and personal competences

2.1. Project and Financial Management

| Apply comprehensive knowledge of project management and business practice for complex engineering activities including risk and change management. | Apply in-depth knowledge of project management and business practice for innovative engineering activities including risk and change management. |

2.2. Communication

| Communicate effectively for complex engineering activities with engineering community and society at large in native and foreign languages. | Communicate effectively for innovative engineering activities with engineering community and society at large in native and foreign languages. |

2.3. Individual and Team Work

| Function effectively both as an individual and as a member of a team in multidisciplinary settings, share responsibilities and capabilities to solve complex engineering problems. | Function effectively both as an individual and as a member of a team and in international settings, share responsibilities for a team work to solve innovative engineering problems. |

2.4. Professional Ethics

| Demonstrate personal responsibility and commitment to professional ethics and norms of engineering practice. | Demonstrate responsibility for both individual and team work and commitment to professional ethics and norms of engineering practice. |

2.5. Societal Responsibility

| Demonstrate knowledge and understanding of the legal, societal and cultural, environmental and health and safety issues relevant to complex engineering practice. | Demonstrate in-depth knowledge of the legal, societal and cultural, environmental and health and safety issues relevant to innovative engineering practice. |

2.6. Lifelong Learning

| Recognize the need for, and have the ability to engage in lifelong learning and professional development. |

Comprehensive and comparative analysis shows that RAEE requirements set for Bachelor competencies in the area of engineering and technologies meet the requirements of the IEA Graduate Attributes and Professional Competencies. The requirements set for Bachelor, Master and Specialist competencies are compatible with the EUR-ACE Framework Standards for Accreditation of Engineering Programmes.

The new RAEE accreditation requirements will be applied to the Bachelor’s, Master’s and Specialist’s engineering programmes developed by Russian HEIs based on new Federal Educational Standards.
References


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Informing engineering education for sustainable development using an deliberative
dynamic model for curriculum renewal

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Abstract: Literature from around the world clearly suggests that engineering education has been relatively slow to incorporate significant knowledge and skill areas, including the rapidly emerging area of sustainable development. Within this context, this paper presents the findings of research that questioned how engineering educators could consistently implement systematic and intentional curriculum renewal that is responsive to emerging engineering challenges and opportunities. The paper presents a number of elements of systematic and intentional curriculum renewal that have been empirically distilled from a qualitative multiple-method iterative research approach including literature review, narrative enquiry, pilot trials and peer-review workshops undertaken by the authors with engineering educators from around the world. The paper also presents new knowledge arising from the research, in the form of a new model that demonstrates a dynamic and deliberative mechanism for strategically accelerating for curriculum renewal efforts. Specifically the paper discusses implications of this model to achieve education for sustainable development, across all disciplines of engineering. It concludes with broader research and practice implications for the field of education research.

Context

Engineering education has come a long way over the last two centuries, rising to the challenge of a series of periods of rapid change and upheaval such as the industrial revolution in 18th Century Britain and the two world wars of the 20th Century (Perkin, 2007). Industrial society and in particular economic demands of the first half of the 20th Century required the invention of modern research and teaching universities and technical colleges. By the end of the Second World War, engineering had become a core profession and a core part of the higher education curriculum, equipping professionals to deliver goods and services in the face of ever-increasing demand across an expanding spectrum of needs. The curriculum has evolved to follow the development of society and industry in order to continue to meet its needs, comprising a complex and highly specialised curriculum. A schematic indicating the progress of these impetuses, or ‘waves of innovation’ as documented by Smith and Hargroves (2005) and based on the work of economist Joseph Schumpeter in the 1940s is shown in Figure 1. Overlaid on the diagram is a sketch of the capacity building transitions associated with these
waves, which the authors have generated from the literature and refined through subsequent peer review by senior engineering educator researchers in the field.

The fifth wave of innovation, which occurred towards the end of last Century, provided a new technological platform and numerous tools for enhancing communications, computation, design, drafting, and data analysis and storage, allowing operations to be significantly improved, and transaction costs to be significantly reduced. However the legacy of this wave is that it has come with an environmental impact that is now becoming evident and beginning to impact on economies and industries (Hargroves & Smith, 2005; Smith et al, 2010; Brown, 2010; Stern, 2006). Subsequently society now faces a host of emerging challenges and opportunities such as reducing greenhouse gas emissions, addressing climate change adaptation needs, dealing with resource scarcity and creating sustainable solutions that decouple economic growth from negative environmental pressure.

![Figure 1: A schematic of curriculum renewal transitions, following significant waves of innovation](Source: adapted from Figure 1.1 in Hargroves and Smith, p17)

In the sixth wave, society is responding to these emerging challenges, with innovations that both build on the previous waves and also significantly reduce environmental pressures (Weizsäcker et al, 2010; Birkeland, 2010), including substantial new knowledge and skill sets across all engineering disciplines in new areas such as resource productivity, energy efficiency, whole system design, and biomimicry - design inspired by nature. Within this context, the system of engineering education faces a significant challenge to provide graduates that can assist industries to reduce such impacts and remain competitive and productive. Indeed, compelling evidence suggests that the emerging imperative for the next decade will be to rapidly embed education for sustainability (EfS) within all education programs, including engineering as a priority (Concoran & Wals, 2008; Jones et al, 2010).

However, research findings from around the world indicate that, to date, the integration of significant new knowledge and skill sets within higher education is limited and at best ad
hoc (for example UNESCO, 2009; RAE, 2007; AASHE, 2010; King, 2008; Wals, 2008) and the traditional time to undertake a full-scale curriculum transition (in the order of two decades) exceeds the available window for equipping professionals with critical new graduate attributes; a significant time lag dilemma facing educators (Desha & Hargroves, 2009). Furthermore, within the literature (for example see Heywood, 2005), there are few examples of systemic curriculum renewal that meet the recommended timeframe of one decade, or discussion of how curriculum renewal could be undertaken over such contracted timeframes.

Research Questions

From the literature review findings, it is clear that a process for curriculum renewal is needed to transition engineering education from ‘old industry’ to ‘new industry’ practice. As highlighted in Figure 2, this process does not need to be the new ‘norm’ for curriculum renewal processes, but rather a transitionary measure, intended to address the time lag dilemma facing higher education. There is an absence of guidance on how to undertake curriculum renewal in a manner that is informed by the surrounding context. Hence, there is a need to improve the process of curriculum renewal to ensure that academics undertake a systemic approach to considering emerging waves of innovation, associated knowledge and skill areas, internal staff capacity, and opportunities to engage with real projects happening on campus and in the community.

Within this context of curriculum renewal theory, the authors sought to provide guidance for academics considering rapid curriculum renewal in urgent and challenging times. Specifically, the authors asked ‘How can sustainability knowledge and skills be effectively embedded into curriculum?’, and further, ‘What can be done to accelerate the process?’ It is considered that these questions are of critical importance to engineering education, given the lack of progress to date in systemic and timely curriculum renewal.

Figure 2: An illustrative curriculum transition curve, showing a period of rapid curriculum renewal from ‘old’ to ‘new’ industry

Theoretical Framework
The theoretical framework for this study was created by finding commonality within the fields of sustainable development science, engineering education and curriculum renewal processes. Ultimately the process of reflexive inquiry provided a supporting role to the literature reviews, which collectively informed the model for rapid curriculum renewal outlined below.

**Methodology**

Given the flexibility in method permitted by researchers such as Denscombe (2007), Layder (1998), and Denzin and Lincoln (2003), this research adopted a relatively unorthodox mixed method through an adaptive and interpretive approach that is situated within a qualitative research paradigm. The research design was iterative and involved multiple methods, drawing from the perspectives of both the ‘armchair theorist’ (i.e. a situational analysis of what is happening to engineering education and why, and considering important elements for curriculum construction) and field-based researcher (i.e. consideration of past and current action within the professional community, indicating emerging professional needs that potentially should be captured in the curriculum reconstruction process).

This approach fits in well with Layder’s continual refinement perspective on qualitative research, where elements taken from existing problematics can, when reorganised and examined in a new order, result in much greater clarity and understanding. The use of multiple methods can also contribute to producing such enhanced clarity with regard to the nature of the problem, the state of engineering education for sustainable development, and mechanisms to address timely and systemic renewal.

This research used three main sources of data:

- Literature from educators describing their experiences and evolving theories, using historical and ethnographic research methods.
- Personal narrative of the authors’ previous project experiences, using reflexive inquiry (i.e. personal review) to undertake document analysis and archival research using content and thematic analysis.
- Peer review from experts in the field regarding the findings from those experiences, to triangulate data sources.

**Major Findings**

The research explored the need for sustainable development knowledge and skills to be embedded within curricula, especially within engineering education. In this case, personal experience suggested a shortfall in engineering education for sustainable development (EESD) and subsequently an urgent need for curriculum renewal.

An integrative literature review of curriculum renewal literature was used to ask whether there was any discourse or inquiry within this literature of the elements of curriculum renewal. From this literature review it was concluded that despite evidence of frustration with the current ‘slow’ process, there is an absence of documented discourse about
actually addressing these potential time constraints, and no alternative is discussed. Indeed, discussions of timing issues are found to have existed for over four decades in the literature, and although the field is focused on the issues of systematic curriculum design and development, it was concluded that there is little consideration for the speed at which curriculum is constructed and implemented or reviewed. While existing models provide significant guidance on systematic curriculum construction, none consider – either explicitly or implicitly – how to vary the pace at which curriculum renewal may be undertaken.

Emerging Elements of Curriculum Renewal

It was hypothesised from the literature review that if there are emergent processes that have not yet been captured in systemic considerations of rapid curriculum renewal, then they should be evident in documented experiences of curriculum renewal. Subsequently EESD literature was reviewed with regard to how rapid curriculum renewal was attempted. It was concluded that there are a number of mechanisms, which could be grouped under a number of themes or ‘elements’ of curriculum renewal. Secondly, higher education literature was reviewed to learn from other professional discipline experiences including law, business, nursing and medicine, where curriculum had clearly been renewed in urgent and challenging times. A process of formal reflective inquiry was undertaken into the authors’ personal experiences in attempting curriculum renewal as an educator and researcher including case studies, pilot trials, and a series of exploratory workshops with engineering educators from around the world to further inform the literature findings. This included reinforcing or contradicting aspects that were already discussed in the literature, and uncovered supporting evidence that was not apparent in the existing literature.

This multi-method exploratory process resulted in the distillation of a set of elements evident in timemanaged curriculum renewal processes, which extends the discourse on ‘curriculum in context’. These include:

- A whole-of-institution curriculum renewal strategy;
- Identification of preferred graduate attributes;
- Mapping of learning outcomes to form learning pathways across programs;
- Assessment of the level of coverage in existing programs (Desha & Hargroves, 2007);
- Developing and updating units, including integrating on-campus and in-community experiences;
- Implementation of updated units throughout program (Paten et al, 2005);
- Staff awareness raising and capacity building;
- Internal and external collaborations, including bridging and outreach activities; and
- Monitoring and evaluation to ensure continual improvement.

Emerging Model for Dynamic and Deliberative Curriculum Renewal
Following extensive development and trialling of a number of elements of curriculum renewal the authors sought to develop a schematic that could demonstrate how these elements could be harnessed to provide a strategic approach to curriculum renewal. This enquiry included analysing a number of earlier models by leaders in the field over the last half century, including Tyler (1949), Taba (1962), Wheeler (1967), Kerr (1968), Walker (1971), Stenhouse (1975), and Egan (1978). It was concluded from this analysis that there is a lack of iteration and systemic dynamism within existing models. Previous models highlighted the importance of various aspects of systemic curriculum renewal, such as forward planning, review, the end-user and consideration of the wider context for learning. However, there was not a whole of system schematic that highlighted the importance of front-end loading the process or the iterative and consultative aspects of curriculum renewal.

Considering this identified gap in conceptualisation, the authors have developed a whole of curriculum interpretation. The resultant circular schematic shown in Figure 3 provides the sense of non-linear dynamism while also demonstrating the need for a deliberative approach informed by a number of factors at each stage of the process. It is intended that the model provide an accessible and useful tool for engineering academic staff to review and update their units, courses and programs.

Figure 3: The Desha-Hargroves Deliberative and Dynamic Model for Curriculum Renewal

Beginning with the curriculum renewal strategy text in the centre of the diagram, the model highlights the importance of having a central point of reference when undertaking systematic curriculum renewal, particularly when multiple educators are involved. The arrows immediately around this text are a reminder that the strategy needs to inform each and every stage of curriculum renewal. In the five larger circles around the central strategy, the five key steps in curriculum renewal are linked in an iterative process that
requires a substantial amount of planning and investigation before the individual units are revised. The arrows interacting with the outer circle are a reminder that this stepped process requires continual monitoring and evaluation, internal and external collaboration, and awareness raising and capacity building among staff. Furthermore, the steps are informed by, and also inform, the three activities in the outer circle.

**Recommendations & Future Research Plans**

In considering potential application of this model for curriculum renewal, it is clear that there are still few catalysts that are large enough to drive substantial curriculum renewal in engineering education. Considering the case of engineering education for sustainable development, it is difficult to predict when the trigger for such renewal will occur globally, but the literature suggests that market and regulatory requirements for sustainability related capabilities will likely escalate within this decade.

With such timeframes in mind, this model may be slightly pre-emptive of a mainstream shift to systemic curriculum renewal towards education for sustainability. However it does provide a useful context and framework for considering how such curriculum renewal might occur once a decision is made to proceed. It also highlights the opportunity for graduate attribute development, mapping and auditing to add value to any existing curriculum renewal process, prior to beginning unit review and development. Further to the development of this model, future research plans will focus on systematically trialling and further elaborating its components and their interaction.

**References**


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Abstract: Europe is nowadays making the transition to the unified European education area following the Bologna guidelines. One of the most important ones is continuous evaluation. In this context test exams are very convenient in order to avoid lecturer work overload. This is due to the capability of automatic production and correction of this exam type. In 2006 our university started the operation of a learning management system named PoliformaT, which is a Sakai customization. This platform gives a very powerful support for lecturers and students, particularly it allows publishing auto-correction exams that can be imported and exported in QTI 1.2 format. We do an extensive use of this feature when computers are available for all students but we still rely on paper exams. We present a tool to automatically correct test exams based on bubble mark answer sheets as a first step to unify QTI and paper test exam production and correction.

Introduction

Nowadays our university is starting the implementation of new curricula based on Bologna guidelines for the unified European high education area. These guidelines are based on three main issues: competence oriented education, student learning autonomy and continuous evaluation. Our work is related to the last, but not least, point. Continuous evaluation is important in order to involve students in the learning process and to permit teachers getting an everyday feedback about how this process is going. The counterpart is an increase in lecturer’s workload. We intend to minimize this drawback by developing information technology tools that will leverage work impact of continuous evaluation.

A straightforward solution is using e-learning platforms support for student’s evaluation. In fact our university started a learning management system (LMS) in 2006 based on Sakai (Sakai, 2011). The LMS is named PoliformaT (Mengod, 2006) and it has a nice support for exam management. Particularly it includes a QTI 1.2 (IMS, 2011) editor named Samigo (Sakai, 2011b) that allows creating self corrected exams with several item types: one choice, several choices, fill-in the blanks, etc. PoliformaT permits importing and exporting QTI 1.2 compliant documents. Exams can be directly edited or they can be generated from
item batteries. Students perform exams on-line via web formularies. We do extensive use of this facility when computers are available for all students (i.e. in lab sessions).

On-line exams are not yet a general solution because sometimes not all students are equipped with a computer and then a classical solution based on paper would be a great complement, particularly if it is integrated with on-line exams management.

In this work we present a tool that produces answer sheet templates, based on fill in bubbles, for test exams that are later automatically corrected. The tool is now in operation offering a basic functionality which is enough in many occasions. It is implemented as a Java applet which implies several good features like multiplatform operation, via Java supporting web navigators, and user transparent application updates. The tool has been selected, among several free and commercial alternatives, for being integrated in PoliformaT as a tool available to the whole university. The implementation technology makes integration easy because Sakai is also made in Java, and integration will make the tool much more convenient to lecturers because many operation details (access to subject IDs, students IDs list, exam publication on student personal folder, etc) will be transparent. It will also make possible a friendly integration with Samigo and QTI exams.

**Test exam correction tool**

Our university offers a service for automatic test exams correction based on a commercial device that uses ad-hoc answer sheet templates. That service has recently collapsed by the increase of test exams performed by lecturers on the new curricula. Because of being directly affected by this situation the authors began the implementation of a tool in order to be able to do test exams independently of the above mentioned service. At the same time the university staff began the searching for the more convenient way to keep providing automatic test exam correction.

The technological approach choose in our implementation is Java applet technology. Partially because of our particular expertise on Java programming but also because of other practical considerations like:

- The main feature of Java is “implement once and run everywhere” which is very relevant due to the platform diversity that exists nowadays (Windows, Linux, MacOS, etc).
- Java has a very rich set of libraries already available in its runtime (JRE), particularly Java 2D for image processing.
- Sakai, and then PoliformaT, is implemented with Java server side technology running on Tomcat web server (also implemented in Java). Then choosing Java to put functionality on the client side is a natural decision that makes client-server functionality allocation tuning very straightforward.
- Applet technology has the added advantage of making installation and update procedures transparent to the user. This is because applets run inside the web navigator and they are loaded from the web server every time they are used. The only disadvantage is that applets should be kept small in order to avoid too long starting time. The previously mentioned feature makes this feasible.
An issue with applets is security; by default Java applets cannot access local resources to avoid exposing the computer to web threats. In order to manage exam correction, access to the local file system is required. In the next section we briefly describe how we have solved this problem.

At present the tool allows exams with up to 4 parts, with a total maximum number of 60 questions with 2 to 4 response options, only one true option question type is supported. The tool provides to the lecturer (the user from now on) two kinds of outcomes:

- **Before the exam.** The user specifies the exam description data (subject name, centre, date, and the number of questions, parts, answer options and exam models).
  The tool produces an **answer sheet template** for every exam model (Figure 1).

- **After the exam.** The user has to provide the filled answer sheets scanned in JPEG format and a text file for every exam model specifying the correct answers. Inside the tool the user indicates for every exam part: the first question number, the maximum score and how many points a wrong answer subtracts to the score.
  The tool produces **corrected exams** in JPEG format that are a replica of the original ones with the inclusion of green squares highlighting correct responses and red squares highlighting the wrong ones. The tool also provides the resulting **score file** in CSV format that includes the computed scores ready to be imported in the university application for score management.

The answer sheet design is based on filling bubbles with marks, which is a very common technology. This is also the way students identify themselves by encoding their ID card number in an ID card panel. To allow including exam information in electronic format, particularly subject name, subject centre, exam date and exam model, we include a QR code (ISO/IEC, 2006). It is used also, in combination with two circular marks at the answer sheet bottom, to register the answer sheet in order to correct image changes (scaling, translation, rotation and distortion) in the scanning process.

The image processing required for filled answer sheet registering and mark identification has been completely implemented by the authors applying state of art image processing techniques (Szeliski, 2010). QR code encoding and decoding is done using Google’s open source software Zxing (Google code, 2011). Basically mark identification is done by computing the gray level median in an area surrounding every bubble. Then an exponential contrast transformation is applied. Finally the gray level values computed for all marks in an answer sheet are classified by a clustering procedure in two groups: marked and not marked.

Google’s QR decoder has proven to be very sensitive to image defects and then we have implemented an iterative image processing, of increasing complexity, in case of failure at the basic QR decoding procedure. After using the tool to correct about 1000 exams we have found that, with a reasonable print quality of answer sheets, the implementation has a failure rate of less than 0.1%. This is a critical parameter because if QR decoding fails then automatic correction is impossible, due to the incapability of answer sheet registering. Bubble mark detection is proven to be even more robust.
Figure 1: Applet corrector user interface. The visualization panel on the left shows a 60 question with 4 options answer sheet template.

Security configuration

The tool operation requires reading and writing files in the user's computer, the main file operations are: writing the answer sheet templates, reading the solution and exam files and writing the corrected answer sheets and the score file. Java security has to be configured in order to allow the corrector applet to access to the local file system.

We have made Java security configuration completely user transparent by implementing a Java application that performs all the required operations. The configuration application is delivered as a ZIP file that contains the Java code packed in a JAR file and two script files, a BAT file for Windows and a shell file that is used in Linux and MacOS. The user simply downloads the ZIP file from a public URL and then the file is decompressed in a folder and after executing the corresponding script file a window is opened asking for accepting security configuration. When the user presses the Accept button, the following two operations are performed:

1. A folder named corrector is created in a predefined location depending on the operating system (i.e. in Windows 7 the path is %userprofile%\corrector). This is the root working folder for the tool, in the sense that every exam will be processed in a subfolder of it. The corrector folder is always created in a location where the user has no file access restrictions.
2. A .java.policy file is created (or updated if there exists a previous one) in order to grant permission to the corrector applet to access to some system properties (i.e. the host operating system name, the user home folder path, etc) and to read, write
and delete files and folders below the root working folder. The .java.policy file is generated using a platform independent syntax.

User interface

The tool is implemented as a web navigator embedded window, which is the most common way of implementing Java applets (Figure 1). The window size is set at the nowadays netbook resolution: 1024x600, this guarantees that the tool can be comfortably used in any computer.

The applet window is composed by two main panels: a viewer panel and a control panel. The user can select what to show in the viewer panel: the answer sheet templates, the exam solutions or the corrected exams. In the upper area of the control panel there is a combo box that gives access to the exam folders. When a new exam is going to be managed then a name for the exam is written in the combo box and after pressing the Enter key a new folder is created. Below the exam folder combo box there are four tabbed panels:

1. **Templates panel.** The user specifies in this panel the exam data, then after pressing the button “Generate templates” an answer sheet template in JPEG format is generated for every exam model, which commonly corresponds to a question and answer option ordering. These templates are located inside the folder Templates contained in the exam folder.

2. **Solutions panel.** The solutions panel allows the user to edit the solutions provided and to activate the solutions, which is a mandatory step previous to correction. After activation a JPEG file is generated in the Solutions folder for every exam model.

3. **Correction panel.** In the correction panel the user has to specify in which question number begins every exam part, the total score and how many points a wrong answer subtracts to the score, both for every exam part. The “Activate criteria” button sets the specified criteria and the “Do correction” button is activated to proceed to correction.

When the correction has finished the corrected exams are shown in the visualization panel where the user can see the highlighted answer in green when right and red when wrong (Figure 2). Four navigation buttons and an exam search utility, based on student ID number, allow controlling the visualization of corrected exams.
Figure 2: Corrected exam sample. Bubble marks are highlighted to indicate right and wrong answers.

4. **Incident panel.** This panel eases the management of wrong encoded ID numbers. In order to allow this operation, a file must be provided containing the ID number and name for every student enrolled in the exam subject. The file is provided by PoliformaT. Using this file the tool gives suggestions about which student corresponds to the wrong encoded ID number. The incident panel also indicates which exams are wrong due to the impossibility of QR decoding or because of being an intruder exam.

The visualization panel synchronizes with the control panel in such a way that the elements shown in the visualization panel correspond to the ones related to the active control panel. A video demo of the tool is available at Gonzalez (2011).

**Conclusions and future work**

The automatic text exam correction tool presented has proven to be very convenient and effective in helping lecturers in the evaluation task. Lecturer's evaluation work has become noticeably increased by the new curricula created to comply with the Bologna
declaration on the European area for higher education. In fact the actual automatic correction service provided by our university has collapsed and, after an evaluation of free and commercial alternatives, our proposal has been chosen to provide this service to the university in a completely autonomous way. During next year the tool will be integrated in our Sakai based e-learning platform. On the student side we have noticed that making easier continuous evaluation enforces its effectiveness in learning, particularly the tool makes feasible to do frequent quick exams (i.e. every two weeks) with a small increase on lecturer’s work.

The tool offers now a basic functionality that has been useful to many lectures. There are many areas for future work that will also be adapted and extended based on the users’ suggestions and needs. Some of the improvements and functionality extensions that we already glimpse are:

- To extend the question types supported to several right answers and numerical response questions, where students have to write a number in a box that the corrector will compare to a solution value or numerical range.
- To make the answer sheet templates more customizable, i.e. numbering every part independently, adapting the sheet layout to the number of answer options, etc.
- At present the tool interface is only in Spanish, we intend to localize the interface depending on the language set up in the user host, at least to Catalan and English.
- To make use of a set of web services that will be implemented in PoliformaT, based on Basic LTI, in order to make as much transparent as possible the access to corporative information (subject ID, student list, student shared folder access, etc). Also corrected exams will be automatically delivered to every student’s personal folder.
- To integrate the tool with Samigo, the QTI exam editor embedded in Sakai. This will be very convenient because the tool will be fed with a QTI file and exam models and solutions specification will be generated automatically. The tool will provide not only the answer sheet templates but also the exam enunciates in high presentation quality PDF format (Gonzalez, 2006).

If we succeed implementing the before mentioned extensions we think that the tool can be proposed to the Sakai community for its inclusion in the platform, and then the tool would be available to Sakai users all over the world.

References


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Does continuous evaluation drive us to mediocrity?

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Abstract: The academic results of a group of 35 students following an Animal Production course of 90 h in the fourth year of Agriculture Engineering School were used in this study. The evaluation of the learning process took into account i) self-assessment tests ii) day to day exercises or problems performed on-site or on-line iii) objective on-line tests and iv) writing test. The scores ranged from 0 to 9.5 in each task whereas the global score ranged from 3.7 to 8.5. The discrimination indexes of each task, except the self-assessment one, were high (averaged 0.48) which indicates their good design. The capacity of analysis and synthesis and the writing skills of the students were evaluated by means of written test and afterwards classified in three groups. No statistical differences were observed among the scores obtained by students of different writing skill abilities. However, the capacity of analysis and synthesis had a significant effect on all task (P<0.01), students with higher analysis capacity obtained 19 to 25% higher scores. The variation of the writing test scores was explained by the analysis and synthesis capacity (18%, P<0.001), by the percentage of on-site attendance (9%, P<0.001) and by the writing skill abilities (2.5%, P=0.0451).

Introduction

Student evaluation becomes more and more difficult when not only knowledge but also skills and abilities must be evaluated. A continuous evaluation system with different kind of works, problems, questionnaires facilitate the competences evaluation and the formative assessment of students, mainly when feedback is used to modify and enhance learning and understanding (Crooks, 2001). Moreover, the use of learning outcomes allows for much more flexibility than is the case in more traditionally designed study programs, because they show that different pathways can lead to comparable outcomes (Tuning project)

The assessment method determines the learning pathway of the students, in such a way that is the fastest way of changing how students learn (Morales, 2011). Agronomy Engineering students should acquire generic competences as writing skills or analysis and synthesis capacity to develop their usual professional activity that must be promoted in mandatory subjects. However, we must pay attention to the evaluation process because it may be inadvertently encouraging surface procedural knowledge memorisation (Goldfinch et al. 2009)

Students look for the most efficient way of arriving to their aims (to pass all the subjects), so they only use complementary resources for learning when they contribute to the final score (Villamide, et al, 2010). Therefore, the relative scores of the different activities on
the final evaluation should be properly set and reviewed to accomplish the learning process. As a consequence of this process, the final score of the students comes from lots of information that should be mathematically processed. There are few failures, but also there are no excellent scores as in more traditional systems. This fact causes misunderstanding among students and teachers because their efforts are not compensated. On the other hand, to disregard this attempt of summative evaluation without an alternative and better system does not seem appropriate.

The objective of the current work was to analyse i) the effect of writing skills abilities and analysis and synthesis capacity on the student scores and ii) the quality of the continuous assessment system through the discrimination index of the different evaluation tasks in a mandatory course of Agriculture Engineer Degree

**Material and Methods**

The academic results of a group of 35 students following an Animal Production course in the fourth year at the Agriulture Engineering School were used in this study. The course takes 90 h of lectures of theory and practices (on-site attendance) consisting of 4 subjects of different duration and evaluated independently. The evaluation took into account i) self-assessment tests performed on Moodle platform ii) exercises or problems performed in the classroom or on-line (from 3 to 12 exercises/ subject), iii) objective on-line test performed in a computer classroom, and iv) writing test. Each task was evaluated from 0 to 10 and 6 points were considered the minimum mark to pass the subject. Discrimination index of each evaluating task has been calculated after classifying the students by the final scores, as the difference between the number of students with scores higher than 6 in the superior and in the inferior sub-group with respect to the number of students per sub-group.

The self-assessment tests on Moodle have a total of 742 items (Table 1), 42% of them of multiple choice type, other 42 % true or false type and the rest are mainly numeric ones. The number of items within a subject, mainly of the multiple choice type, was proportional to the subject load. The number of tests proposed during the course was 21, from 3 to 8 for each subject and accounted for 5% of the final score. The students can do each test as many times as desired, but three times is recommended to cover the entire topic.

<table>
<thead>
<tr>
<th>Item number</th>
<th>Multiple choice</th>
<th>True-false</th>
<th>Numeric</th>
<th>other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swine production</td>
<td>185</td>
<td>88</td>
<td>48</td>
<td>45</td>
</tr>
<tr>
<td>Poultry production</td>
<td>168</td>
<td>64</td>
<td>82</td>
<td>22</td>
</tr>
<tr>
<td>Cattle production</td>
<td>226</td>
<td>125</td>
<td>87</td>
<td>13</td>
</tr>
<tr>
<td>Sheep production</td>
<td>163</td>
<td>37</td>
<td>93</td>
<td>14</td>
</tr>
</tbody>
</table>

The exercise and problems performed on-site or on-line varied both in number (from 3 to 10 for each subject) and depth, from a simple mathematic calculation performed and corrected individually in the classroom, to a large study looking for relevant information in the library and presented as a report. The importance of each activity in the final task...
depends on the competences that could be evaluated, and account for 30% of the final mark.

The objective on-line tests were performed simultaneously for each group in a computer classroom using the test section of Moodle with a maximum time of 30 to 40 minutes. The number of items varied from 12 to 20 for each test (Table 2), mainly of multiple choice type with negative score for incorrect answers to correct the random effect. Also, match type items, or numeric ones, that were not penalized for incorrect answers were included. These objective on-line tests accounted for 32.5 to 45% of the final score.

| Table 2: Number and type of items of each subject used in objective on-line tests. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                                 | Number of items | Multiple choice | Match | Numeric | True or false |
| Swine production                | 16              | 10              | 3     | 3      | 2              |
| Poultry production              | 15              | 9               | 3     | 2      | 1              |
| Cattle production               | 20              | 15              | 3     | 2      | 1              |
| Sheep production                | 12              | 6               | 5     | 1      | 1              |

Finally, the writing tests included from one to three questions in which students had to develop a subject and/or analyze and discuss data. They accounted for 20 to 32.5% of the final score.

On the other hand, the writing skills and the capacity of analysis and synthesis of 33 students who follow continuous assessment were evaluated by means of a specific writing test where they have to write a letter and analyze two practical cases. Both competences were evaluated using two different rubrics with 3 and 4 categories, respectively and 3 levels of competence (Villa and Poblet, 2007). Afterwards, values obtained for writing ability and analysis and synthesis capacity were related to the marks obtained by the students by means of correlation and regression analysis. These ability values were classified in three groups and an analysis of variance was performed using the SAS program (SAS, 1990).

**Results and Discussion**

**Effect of writing skill abilities and analysis and synthesis capacity on the scores**

The effect of students’ classification according to their writing skills ability and analysis and synthesis capacity on the marks obtained during the year is shown in Table 3. No statistical differences were observed among the marks obtained by students of different writing skill abilities in any of the task evaluated, probably because the writing skills of the students were relatively high (7.59 out of 10, as average) and with low variation (15% coefficient of variation). The capacity of analysis and synthesis of the students was similar but presented more variation (20%) among students than the writing skills ability. Analysis and synthesis capacity had a significant effect (P<0.001) on the marks of students performing all kind of tests. Thus, the students with high analysis capacity had from 19 to 25% higher marks than those classified as with low analysis and synthesis capacity. Most
important differences were found for continuous exercises and writing test marks where this competence should be applied deepest.

In fact, the variation of marks in the writing tests was mainly explained by analysis and synthesis capacity of students (18%, $P<0.001$) by the percentage of on-site attendance (9%, $P<0.001$) and by their writing skill abilities (2.5%, $P=0.0451$). However the marks of objective tests of Moodle were only related to analysis and synthesis capacity, that explained only 6% of its variation ($P<0.006$).

Table 3. Effect of writing skills ability and analysis and synthesis capacity of students on the marks obtained in the different tests.

<table>
<thead>
<tr>
<th></th>
<th>Writing skills ability</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High (n=8)</td>
<td>Medium (n=14)</td>
<td>Low (n=11)</td>
</tr>
<tr>
<td>Self-assessment test</td>
<td>8.61</td>
<td>7.99</td>
<td>8.26</td>
</tr>
<tr>
<td>Continuous exercises</td>
<td>8.05</td>
<td>7.01</td>
<td>6.87</td>
</tr>
<tr>
<td>Objective test (Moodle)</td>
<td>6.24</td>
<td>5.65</td>
<td>5.68</td>
</tr>
<tr>
<td>Writing test</td>
<td>7.77</td>
<td>6.86</td>
<td>6.68</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Capacity of analysis and synthesis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High (n=11)</td>
</tr>
<tr>
<td>Self-assessment test</td>
<td>8.67</td>
</tr>
<tr>
<td>Continuous exercises</td>
<td>8.21</td>
</tr>
<tr>
<td>Objective test (Moodle)</td>
<td>6.32</td>
</tr>
<tr>
<td>Writing test</td>
<td>7.72</td>
</tr>
</tbody>
</table>

One of the common problems both in objective and essay tests is the interpretation of questions (Biggs, 1999) or problems (Diefes-Dux et al., 2009) by the students. Higher analysis capacity implies a better understanding of questions and organization of the answers. The influence of the on-site attendance on writing tests should be related to the learning activities performed on-site. This is because on-site attendance allows an overall analysis of the problems with the hypothesis cause-effect, their relationships with previous concepts and the possible solutions discussed directly with the students. This also provides a feedback to the student, important for their own progress with the subject. According to the results observed by Goldfinch et al (2009), our students also make most of their mistakes in the problem procedures, mainly caused by deficiencies in conceptual knowledge.

Quality of the assessment system

The summative assessment of the current subject relies mainly on two kind of tests: objective ones (mainly multiple choice tests, Table 2) performed on-line, and writing tests (essay type, case study). These try to meet all topics using short answer tests, where students use surface strategies of learning, and to ensure depth learning with essay type tests (Biggs, 1999). Moreover, other learning activities were proposed along the year (self assessment tests and on-site or on line exercises) in order to guide and improve the learning process (Valero and Díaz de Cerio, 2005) although they were also qualified.
One objective criterium of evaluating the quality of a test as mean of evaluation is its discrimination capacity. In the current work, the discrimination index of the different evaluation tasks was calculated with respect to the final scores (Table 4) as they were items of a simple test. The self-assessment test Moodle did not discriminate among the best and worst students. They are useful for formative assessment, mainly when feedback is included in the items. All the students following continuous assessment perform these tests, although some of them only try to get the maximum score, because they perform the tests only once if they have the maximum mark. An alternative way of scoring this test should be their execution or not, but Moodle does not provide the number of times that a questionnaire is performed. This might limit the interpretation of the results and also could have a negative impact on the discrimination index of these tests. Students spend about 2.8 h a week as average (Villamide et al., 2008) performing and reviewing these tests. From teacher's point of view, its utilization is very fast and easy once the items have been implemented.

Table 4: Discrimination index of the different evaluation task for each subject

<table>
<thead>
<tr>
<th>Subject</th>
<th>Self-assessment</th>
<th>On-site and on-line Exercises</th>
<th>Objective test (Moodle)</th>
<th>Writing Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swine production</td>
<td>0.00</td>
<td>0.30</td>
<td>0.40</td>
<td>0.70</td>
</tr>
<tr>
<td>Poultry production</td>
<td>0.17</td>
<td>0.75</td>
<td>0.50</td>
<td>0.25</td>
</tr>
<tr>
<td>Beef and dairy production</td>
<td>0.08</td>
<td>0.25</td>
<td>0.83</td>
<td>0.33</td>
</tr>
<tr>
<td>Sheep production</td>
<td>0.25</td>
<td>0.83</td>
<td>0.08</td>
<td>0.50</td>
</tr>
</tbody>
</table>

On-site and on-line exercises had high discrimination index (from 0.25 to 0.83), the highest for two of the subjects with the lowest number of exercises, probably because it was positively correlated to the proportion of on-site attendance ($r=0.54$, $P<0.05$). Although the characteristics of these activities were very variable (from short exercises performed and corrected in the classroom to long reports linked in Moodle platform), all received qualitative feedback about the learning outcomes.

Writing test had a high discrimination index for all subjects (more than 0.25), whereas objective test had very good discrimination index except for the subject that included less questions and with lower proportion of multiple choice questions. Students did not received individual feedback of these tests unless they asked for them to the teacher. In some occasions a general feedback of the writing test was sent by mail when some common errors or misconceptions were observed. Although the correlation between general scores of self-assessment or continuous exercises and objective or writing tests were relatively low (from 0.08 to 0.52), in a previous work (Villamide et al., 2010) higher scores (2.2 points, as average) for items evaluating a same topic had been observed for students that had performed the corresponding learning activities respect to those that had not performed. Therefore, concerning discrimination index, all the task except the self assessment seems to be correctly designed. In fact, 74% of the students following the continuous assessment pass the subject with a minimum mark of 6 to avoid doing the final exam.
The final score of the students comes from a complex algorithm, where all the evaluated tasks affect in higher or lower extent. In each task the scores ranged from 0 or 2 to 9.3 or 9.5 whereas in the global score it ranged from 3.7 to 8.5. The marks of self-assessment and continuous exercises had opposite effect in the final score of students with the highest and lowest marks both in objective and writing tests. For students with higher marks, the self-assessment and mainly the continuous exercise marks decreased the final score, whereas for those students with low or medium marks in the most formal test, the marks of the continuous assessment increased the final scores, making in some cases possible to pass the subject. This clustering effect of the scores distribution towards the average is one of the reasons why the best students complain of this assessment method. Similarly, teachers that spend too much time evaluating and scoring different tasks, observe that the final scores of their students are as average higher than with final assessment, but without excellent marks. It looks like the learning process does not discriminate properly and the student scores tended to mediocrity.

Conclusions

Analysis and synthesis capacity has higher impact on the student scores than writing skills abilities. Our continuous assessment process which included several different tasks with high discrimination indexes led to student scores clustering around the average and hence to mediocrity.

References


Morales, P. (2011) Evaluación de los aprendizajes: Nuevos enfoques del EEES. Instituto de Ciencias de la Educación, UPM.


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http://www.upm.es/innovacion/cd/09_cyj/documentos/


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An improvement of academic results by a self-study methodology in Transportation Engineering subject

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Spain

Abstract: This paper presents the results of a change in methodology when teaching the subject “Transport Engineering” in the BS in Industrial Engineering, in addition to the implementation of a continuous evaluation system. The change in methodology consists in the development of a study procedure for the students and the assessment of student capacity for analysis and synthesis. To implement these developments, a self-study guide has been prepared with a specification of objectives according to the Bloom taxonomy, knowledge required and necessary resources; self-evaluation tests and problems specifically designed towards the learning objectives. Midterm tests have been carried out and their results have been compared with two control groups following the traditional methodology teaching. The statistical analysis of the data collected and the comparison between the different groups indicates that the methodology and the on-line material have been useful to the students, achieving on average and improvement in academic performance.

Introduction

The academic performance is intimately related with the quality of the education and this depends, on a great basis, on the didactic and evaluation methodologies applied. Despite of this fact, the methodology of education has remained invariable in many University institutions, on which it can be appreciated, on another hand, an extraordinary evolution of other aspects of academic life (Aparicio and González, 1994). With the renovation of the training as raised in the frame of the process known as “Bolonia”, it is intended, amongst other objectives, the evolution from a education that has as its axis the contents of the subjects, and the exposition of them by the teacher, towards a new strategy centered on the learning objectives, the active participation of the students in their achievement, and the intellectual interaction with the students by means of debates, non autonomous problem solving as well as other support and evaluation activities. In this context, it can be framed this teaching experience which combines two strategies: an educational methodological change in teaching to promote active learning by defining the learning objectives as innovation factor and the implementation of a continuous evaluation system of the subject “Transport Engineering”, on the 9th semester of the degree in Bachelor in Industrial Engineering intensifications of Industrial Organization, Construction and Manufacturing on the course 2010-2011 (from this on will be referred as the “experimental group EG”) (Aparicio et al., 2010). The methodological change has consisted in the development of a methodology for students study and the evaluation of competences as analysis and synthesis capability, the ability to solve problems individual and collectively, according to the objectives stated on the methodology. For the
implementation, it has been elaborated a self-study guide, where it have been specified the objectives to be met, the required knowledge and the resources to achieve them, it have been designed problems oriented towards the specific learning objectives and it has been registered and later on treated the monitoring sheets filled up by the students with the level of objective compliance and dedicated time for study. All these teaching material was managed by the e-learning system AulaWeb which is an interactive web-based teaching and learning system with password authentication, web publishing facilities, self-assessment, and communication tools, developed by the División de Informática Industrial of the Universidad Politécnica of Madrid (UPM) (Martínez, R. and García -Beltrán, A., 2001). On these monitoring sheets the students should notice the objectives non-achieved in order to develop them at the sessions organised in form of tutorship classes by the professors. The monitoring sheets submitted by the students at tutorship classes have been statistically analysed with the target of obtaining the assessment elements of the education experience and to establish the conclusions for the improvement of the developed system. For the selfevaluation, it have been designed specific tests of each of the parts in which have been structured the experience and it has been carried out a partial control exam in the frame of the continuous evaluation, whose results have been compared with the results achieved on the continuous evaluation by those groups following traditional methodology (from this on will be referred as “control group CG). Finally it has been carried out a survey to extract information regarding the valuation of the experience by the students.

Self-study methodology

To prepare the self study guide, it has been defined, at a first stage, the fundamental elements of the developed methodology:

- The self-study areas have been structured in thematic blocks (BT), and these, later on, in learning units (UA).
- A thematic block (BT) is understood as a contain unit with characteristics and learning objectives differentiated of the rest of the theme and, once identified, allows the explaining and solving of a significative group of specific problems without the need, at least in a significative manner, of the resources offered by other thematic blocks.
- The learning unit is (UA) is understood as a component of a thematic Block, integrated by contents whose study in a together manner favours the comprehension of a relevant phenomena for the achievement of the objectives of the BT.
- For each learning unit it were formulates general and specific objectives, classified according the 4 first categories of Bloom's taxonomy (Bloom, B. S., 1956): Knowledge (CON), Comprehension (COM), Application (APL) and Analysis (ANA).

The theme chosen for the experience has been theme 3 of the subject transport Engineering: Road Transport. Vehicle: Performance, Braking and Lateral behaviour. It has been structured in 3 thematic blocks: Performance calculation (BT1), Braking (BT2) and lateral dynamic (BT3). Each of them has been divided in several learning units (UAs).
For each BT and UA it have been defined the specific and general objectives, and linked to them, it has been indicated the information regarding the related contents present at the subject text and some other chosen references. For application objectives, it was indicated the exercises that would help to develop the capabilities required for the objective. All this information, properly codified, has been documented in the self study guide (GA) and a learning control sheet (HGA), which has been designed for this purpose together with the instructions for its completion. At these sheets the student pointed out the time (in hours) dedicated to the study of each UA, the key points of the objective and the detected difficulties or other relevant coded matters for the learning. In case of not having sufficiently completed the learning objectives, the students should increase the efforts and resources dedicated (time of study, tutorship's ...) before starting the study of a new unit or thematic block. Once completed the study of the UA and properly achieved the objectives and required learning level, the students could perform self-evaluation tests of the respective unit. These auto-evaluation tests did not pretend to cover exhaustively all the objectives; it was a sampling for knowledge and capabilities verification, developed in a similar manner to the subject evaluation exam, and that have not been considered for evaluation purposes as it was the partial evaluation control of the continuous evaluation process.

Describing the experience

The teaching material for theme 3: Road Transport. Vehicle: performance, braking and lateral behaviour, designed to implement the self-study methodology described previously, was managed by the e-learning system AulaWeb of the Universidad Politécnica of Madrid (UPM). In this paper are presented the results of the evaluation of the innovative learning methodology effectiveness, in comparison with traditional methodology teaching: the degree of achievement of the objectives outlined in the Guide, and the average time (in hours) devoted to the study of each learning unit for the Experimental Group as well comparing group means obtained by students in the midterm theme 3 evaluation). For this purpose, the comparison will be determined within three groups as described in Table 1. Besides, it is shown the evaluation survey results made within the EG’s students.

Table 1: Experimental and Control Groups description.

<table>
<thead>
<tr>
<th></th>
<th>Experimental Group</th>
<th>CG1-Control group 1</th>
<th>CG2-Control group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nº of students of Industrial Engineering</td>
<td>74</td>
<td>70</td>
<td>92</td>
</tr>
<tr>
<td>Intensifications</td>
<td>Industrial Organization EG-1693 (61%), Construction EG-1393 (27.4%), and Manufacturing EG-1993 (11.6%).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Course:</td>
<td>2010-2011</td>
<td>2010-2011</td>
<td>2009-2010</td>
</tr>
<tr>
<td>Teachers:</td>
<td>1 and 2</td>
<td>3 and 4</td>
<td>1 and 2</td>
</tr>
<tr>
<td>Methodology</td>
<td>Self-study</td>
<td>Traditional</td>
<td>Traditional</td>
</tr>
</tbody>
</table>

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Results

Specific targets and knowledge degree obtained during the self-study process in EG

As a result of the self-study process each student of the EG group has submitted the monitoring sheets to be statistically analysed to obtain assessment elements of the education experience and to establish the conclusions for the improvement of the developed system.

The degree of achievement of the objectives outlined in the Guide and the average time (in hours) devoted to the study of each learning unit are shown in Table 2 and 3. The categories TL = Fully Achieved, PL = partially achieved, D = With Difficulties - Consultation, indicate the self-declared level of achievement of objectives. Over a third (34.4%) of participating students consider to have fully achieved the learning objectives and 46.2% have done so partially of studying the thematic UA of BT1. The percentages of students who say have succeeded with difficulty and therefore need consultation or tutoring is on average 13.4%. The average total number of hours studying was 9 hours. Related to BT2 over a third (37.8%) has achieved the learning objectives and a 15.5% has need tutoring sessions. The average total number of hours studying was 5 hours, below the time dedicated to the self-study of contents of BT1. The total achievement of the specific objectives for BT3 is below the two previous BT’s and rose 27.2%. For this block it is higher the percentage of students requiring tutoring session, although the average total number of hours studying was 7 hours, besides the fact that there is more heterogeneity in the measures of time dedicated to study.

Table 2: Level of achievement (in %) of learning objectives (TL = Fully Achieved, PL = partially achieved, D = With Difficulties - Consultation).

<table>
<thead>
<tr>
<th></th>
<th>UA1</th>
<th>UA2</th>
<th>UA3</th>
<th>UA4</th>
<th>UA5</th>
<th>GLOBAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TL (%)</td>
<td>51.8</td>
<td>31.7</td>
<td>32.4</td>
<td>21.5</td>
<td>34.4</td>
<td></td>
</tr>
<tr>
<td>PL (%)</td>
<td>40.8</td>
<td>50.8</td>
<td>47.4</td>
<td>45.7</td>
<td>46.2</td>
<td></td>
</tr>
<tr>
<td>D (%)</td>
<td>7.5</td>
<td>11.9</td>
<td>13.3</td>
<td>21.0</td>
<td>13.4</td>
<td></td>
</tr>
<tr>
<td>BT2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TL (%)</td>
<td>58.3</td>
<td>28.5</td>
<td>35.4</td>
<td>29.2</td>
<td>37.8</td>
<td></td>
</tr>
<tr>
<td>PL (%)</td>
<td>37.5</td>
<td>49.0</td>
<td>38.2</td>
<td>53.5</td>
<td>44.5</td>
<td></td>
</tr>
<tr>
<td>D (%)</td>
<td>4.2</td>
<td>20.8</td>
<td>21.5</td>
<td>15.3</td>
<td>15.5</td>
<td></td>
</tr>
<tr>
<td>BT3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TL (%)</td>
<td>44.7</td>
<td>30.7</td>
<td>21.9</td>
<td>24.3</td>
<td>14.5</td>
<td>27.2</td>
</tr>
<tr>
<td>PL (%)</td>
<td>40.8</td>
<td>46.5</td>
<td>62.3</td>
<td>52.0</td>
<td>55.9</td>
<td>51.5</td>
</tr>
<tr>
<td>D (%)</td>
<td>14.5</td>
<td>22.8</td>
<td>15.8</td>
<td>23.0</td>
<td>28.9</td>
<td>21.0</td>
</tr>
</tbody>
</table>
Table 3: Descriptive statistics of time devoted to study of the UA's (in h).

<table>
<thead>
<tr>
<th></th>
<th>UA1</th>
<th>UA2</th>
<th>UA3</th>
<th>UA4</th>
<th>UA5</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT1</td>
<td>1.94</td>
<td>1.94</td>
<td>3.02</td>
<td>2.06</td>
<td></td>
</tr>
<tr>
<td>BT2</td>
<td>0.85</td>
<td>1.83</td>
<td>0.96</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>BT3</td>
<td>0.95</td>
<td>1.21</td>
<td>1.44</td>
<td>1.47</td>
<td>1.76</td>
</tr>
</tbody>
</table>

In the analysis of data by groups, it can be highlighted the fact that the EG-1693 (Organization) has engaged in general more time to study in all the topics. In particular, this group has spent an average of 3.32 hours of self-study of UA1 of the BT1, compared with 2.65 h of the EG-1393 (Construction) and 1.57 hours spent by the group EG-1993 (Manufacturing). It is also greater the variance and range of hours of study for students of this group, compared to the rest of participants in the experience. But there is no correlation between time spent and the average score for the specialty of Organization as the average score on the midterm exam is lower than the one obtained by the specialty of Construction.

The evaluation survey results

The educational experience has been evaluated by conducting a survey in which questions have been made on key elements that constitute the proposed methodology as part of the self-study guide. In the survey, it was desired to assess to what extent the method has contributed to the achievement of learning established in the general and specific objectives and to guide and facilitate the personal work and self-verification of successive achievements in study sessions. Four levels of responses were defined: High (H), Medium (M), Low (L), None (N). The results (in % of total responses) for the survey are shown in Table 4.

Students show a high degree of satisfaction for their participation in the educational experience and generally it has been assessed as a very helpful self-study guide. The objectives have allowed knowing in advance the type of learning expected for 71% of the students. The self-assessment tests appear adequate to 82% of the students. The issues proposed for the evaluation of the objectives of the experiment have been assessed positively by 96% of responses. The sessions of analysis of the degree of achievement of the objectives have been seen as very useful in 86% of responses. 72% of the responses considered that the methodology has enabled significant improvements in the teaching of engineering.

Table 4: Results of the satisfaction survey

<table>
<thead>
<tr>
<th>ASPECT TO BE ASSESSED</th>
<th>H</th>
<th>M</th>
<th>L</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>The self-Study Guide as a whole has been useful to guide</td>
<td>36%</td>
<td>39%</td>
<td>21%</td>
<td>4%</td>
</tr>
<tr>
<td>the learning of subject</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The distribution of thematic blocks and learning units can</td>
<td>64%</td>
<td>36%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>be considered adequate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Academic results. Experimental versus control group

This section presents the results of midterm theme 3 evaluation. As indicators of student performance, we have comparing mean groups for scores for three classes: EG, CG1 and CG2 in Table 5.

The test hypothesis is that the values obtained from two different groups are equal. If the groups are independent of each other and the data are normally distributed in each group, then a group t test can be used as it was done in this work using the SAS/ETS PROC TTEST from SAS Institute Inc, SAS V9.2. The "Equality of Variances" test results show that the assumption of equal variances is reasonable for these data (the Folded F statistic F' = 1.32, with p=0.2500). The assumption of normality has been checked using PROC UNIVARIATE; so the appropriate test is the usual pooled test, which shows that the average scores of partial exam of Theme 3 for CG1 and EG as well CG2 and EG are significantly different at the 5% level (t=-4.52, p=0.0001 for the former and t=-3.05, p=0.0027 for the latter), So the experience can be considered positive because it has contributed to improve academia results in the midterm exam.

Additionally in Fig 1, it is shown the percentage of students (%) belonging to EG and CG1-CG2 groups achieving marks of <5, % marks between 5 and 7 and % with marks greater than 7. Additionally it shows the number of students that have not followed the partial evaluation. In the experimental group the percentage of students with a grade greater than 7 has doubled the 24% observed in CG2. The average percentage of EG students who have chosen not to run this midterm exam has decreased with respect to that in CG1 and CG2.

### Table 5: Mean marks. Midterm Theme 3 exam. Experimental Group versus Control groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG1</td>
<td>5.65</td>
</tr>
<tr>
<td>EG</td>
<td>7.16</td>
</tr>
<tr>
<td>CG2</td>
<td>6.02</td>
</tr>
</tbody>
</table>

Additionally in Fig 1, it is shown the percentage of students (%) belonging to EG and CG1-CG2 groups achieving marks of <5, % marks between 5 and 7 and % with marks greater than 7. Additionally it shows the number of students that have not followed the partial evaluation. In the experimental group the percentage of students with a grade greater than 7 has doubled the 24% observed in CG2. The average percentage of EG students who have chosen not to run this midterm exam has decreased with respect to that in CG1 and CG2.
Conclusions

The comparison of results obtained for the EG with those obtained by CG indicates the improvement of academic performance. The results of control of self learning by students indicate that a high percentage of students have fully or partially achieved the objectives. Although there are areas for improvement, the teaching experience has been assessed very positively by the vast majority of the students involved in it, as the higher degree of satisfaction of participant shows.

By the statistical analysis done it can be highlighted the results are statistically different within the three groups (experience versus control groups), for the indicator midterm theme 3 exam indicating there was an improvement of the global academic performance.

Porcentual distribution by mark intervals obtained in the midterm Theme 3 exam. Experimental group (EG) – Control Group 1 and 2

References


Bloom, Benjamin S. (1956). Taxonomy of Educational Objectives Published by Allyn and Bacon, Boston, MA. Copyright (c) 1984 by Pearson Education.

SAS Institute Inc. SAS/ETS PROC TTEST. Program SAS V9.2

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Engineering in an Elementary Setting: An Analysis of Context Maps

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Abstract: With the recent push for STEM (science, technology, engineering and mathematics) education in the pre-college setting, engineering design is emerging as a critical curricular component. Pre-college engineering instruction, including engineering design, can influence students’ interest in STEM and ultimately career choices towards STEM fields. In this study, students in grades two to five completed context maps after participating in a pre-college engineering intervention. Using the Contexts of Meaning as a theoretical framework, context maps were coded using the five Contexts of Meaning categories (i.e., semantic knowledge, personal experiences, metaphors, interpretive frameworks, emotions-values-aesthetics), and with an additional category of “misinformation.” Student maps revealed more recordings of personal experiences than semantic knowledge, meaning students began drawing their own meaning, interpretations, comparisons, and inferences about engineering after the intervention. Additionally, students drew most heavily upon the General Engineering interpretive framework. Future research calls for a secondary coding system in order to gain a more nuanced understanding of student knowledge and meaning.

Introduction

With the recent push for STEM (science, technology, engineering, mathematics) education in the pre-college setting in the USA, engineering design is emerging as a critical curricular component (Welty, 2007; Gattie & Wicklein, 2005). Pre-college engineering instruction, including engineering design, can influence students’ perceptions of STEM, which has the potential to later positively influence students’ career choices in these fields (Cook, Wright, Shumway, & Terry, 2009; Welty, 2007). According to Strobel, Weber, Dyehouse, and Gajdzik (2011), STEM instruction at the elementary (primary) level can influence students’ perceptions about the appeal, accessibility, and potential career options of STEM disciplines. Too often, in elementary (primary) classrooms throughout the USA, the “E” in STEM is ignored (Strobel et al., 2011) and young students do not have the opportunity to develop interest and talents in this area. “Engineering is meant to provide a context or vehicle to learn other academic disciplines while introducing integrative concepts and competencies, such as optimization, modelling, constraints, design, problem solving, and critical thinking” (Strobel et al., 2011, p. 3). This conception of engineering was put into practice in an elementary (primary) setting in the USA.

Pre-college students often have early misconceptions about engineers and engineering. Many students believe engineers are involved primarily with building and repairing
buildings, electronics, and automobiles. Several assessments have been used to better understand students’ perceptions of engineers and engineering. One such assessment is the Draw an Engineer Test (DAET) (e.g., Capobianco, Diefes-Dux, Mena, & Weller, 2011; Oware, Capobianco, & Diefes-Dux, 2007; Knight & Cunningham, 2004). This test, along with the typical accompanying interview, provides interesting insights into students’ understanding of engineering, however, it is time-consuming and labour-intensive to administer and score. Additionally, the DAET allows for only one snapshot into students’ conceptions of engineering since students are instructed to draw just one pictorial representation of an engineer. The field of pre-college engineering education research needs to explore additional and different ways to assess students’ learning of engineering.

The theoretical framework that guided this study was the Contexts of Meaning framework (Bloom, 1992). Additionally, the methodological framework used to frame this study was an Action Research framework (O’Brien, 1998). Though not all aspects of Action Research were employed, many were, including teacher as researcher, critical reflection, and an end goal of promoting, improving, and sustaining engineering education and engineering literacy for pre-college students.

The following research questions guided our study:

1. What engineering meaning, based on the Contexts of Meaning framework, emerged from the students’ context maps after the engineering intervention?
2. How did the students’ expressed engineering meaning relate to the engineering intervention objectives?

In addition, the following process question was utilized: How useful were context maps to detect students’ meaning associated with engineering?

Given existing shortcomings, it was important to implement an assessment strategy that allowed for expression of varying facets of student knowledge. The context map assessment allowed for investigation into the meaning students retained and created after an engineering intervention. This is important to engineering education since across the USA, and worldwide, engineering interventions at the pre-college level are becoming more prevalent, and reliable assessment strategies that help demonstrate student knowledge are critical to the refinement of said interventions.

**Literature Review**

Engineering at the elementary (primary) level is a relatively new concept in the United States and in other cultural contexts (Clark & Andrews, 2010). Often, students are not exposed to engineering curriculum until high school (secondary school) or even college or university. With the recent interest in early exposure to engineering, researchers are investigating student conceptions about engineers. Many researchers find that young students hold the belief that engineers are mechanics, labourers, and technicians (Capobianco et al., 2011; Cunningham & Knight, 2004). Engineering interventions are needed to help dispel these misconceptions. However, with interventions, assessments are necessary. The Draw an Engineer Test (DAET) is a popular tool used to assess students’
ideas about engineers and engineering (Capobianco et al., 2011; Oware et al., 2007; Knight & Cunningham, 2004); Students are asked to draw a pictorial representation of an engineer and then answer the question, “What is your engineer doing?” The DAET is a time-consuming assessment as it often requires an accompanying student interview to more completely understand student ideas. When completing the DAET, students generally spend 20 to 30 minutes drawing their picture of an engineer, and then spend another 20 to 30 minutes completing the interview with the researcher. Context maps offer a faster alternative to the DAET since they do not require an accompanying interview.

**Context and Theoretical Framework**

When assessing students’ knowledge, or trying to investigate what students find meaningful, sometimes knowledge other than semantic must be explored (Bloom, 1995, 1992). Semantic knowledge consists of formal knowledge, or what is directly taught to students. Traditional concept maps focus on the mapping of semantic knowledge and follow a more systematic structure (Novak & Canas, 2008) than do context maps, which allow for free expression of student ideas (Bloom, 1992). In his 1995 study, Bloom used context maps to assess first and fifth grade students’ knowledge of “issues facing the world” and “forests”. In his analysis, Bloom elected to focus on students’ personal experiences, metaphors, interpretive frameworks, and emotions-values-aesthetics, and chose not to focus on the semantic knowledge represented in the context maps. These context maps provided, “a glimpse of a child’s thinking and knowledge” (Bloom, 1995, p. 172). Bloom has shown that context mapping and the Contexts of Meaning Framework, “describe the natural processes involved in meaningful learning” (Bloom, 1992, p. 412). Context maps allow meaning to emerge in an organic, natural way, with the student creating meaning out of learning as opposed to having the student work within a constrained structure.

The theoretical framework that guided the content of our assessment was the Contexts of Meaning Framework (Bloom, 1992, 1995). This framework incorporates semantic knowledge, personal experiences, metaphors, interpretive frameworks, and emotions-values-aesthetics (Bloom, 1992, 1995). Semantic knowledge is considered formal knowledge and a representation of information directly taught to students. Personal experiences are expressed by students elaborating on, interpreting, comparing, or inferring about information presented during a lesson. Personal experiences provide important insights into those concepts that students find meaningful. Metaphors allow for comparison of ideas by linking the concepts. This provides opportunities for students to express ideas that link new knowledge with similar prior knowledge. Interpretive frameworks are the “big picture” themes about what students choose to include in their context maps. Interpretive frameworks, “act as guides to the processes involved in interpreting and making sense of the world” (Bloom, 1992, p. 408). Finally, emotions-values-aesthetics responses are examples of students’ own reactions to the subject, including projecting how someone or something else will react or feel. These responses are filled with emotion, and include describing words and value statements.
Methodological Framework and Research Design

Methodological Framework

The methodological framework used in this study was Action Research. “Action research is learning by doing - a group of people identify a problem, do something to resolve it, see how successful their efforts were, and if not satisfied, try again” (O’Brien, 1998, p. 3). In the case of the context map study, a facilitator conducted an engineering intervention with students in grades two to five (primary school). During the course of the year, curriculum was refined and improved to best meet student learning needs. The intervention was created based on several years of pre-college engineering education research conducted by the Institute for P-12 Engineering Research and Learning (INSPIRE), housed at Purdue University. INSPIRE has several long-term goals, including improving pre-college engineering literacy and providing early engineering interventions.

Participants

The research took place in an independent school in the Midwest of the USA. Students were involved in an engineering class two days a week, with each engineering session lasting fifty minutes. The students were taught using a Discovery Learning approach, with a focus on allowing students the freedom to explore and interpret information to allow for construction of individual knowledge (van Joolingen, 1999). The participants were second through fifth grade students (approximately aged seven to eleven years). Within each of the third, fourth, and fifth grade classes, certain students were identified as “Affinity” students. These students exhibited particular affinity towards engineering as demonstrated through higher order questioning, excellent leadership and communication, an ability to function creatively and effectively with constraints through iterative design, and possessing a keen ability for problem solving. The students were grouped into four random groups, with each group receiving engineering instruction for a quarter of the school year (i.e., the first group receives engineering during the first quarter; the second group received engineering during the second quarter, etc.). The focus of this paper is on the first quarter students. Participant information can be found in Table One.

<table>
<thead>
<tr>
<th>Grade Level</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>3rd</td>
<td>7 (*1)</td>
<td>8 (*4)</td>
</tr>
<tr>
<td>4th</td>
<td>7 (*2)</td>
<td>8 (*2)</td>
</tr>
<tr>
<td>5th</td>
<td>7 (*2)</td>
<td>7 (*4)</td>
</tr>
<tr>
<td>Total</td>
<td>29 (*5)</td>
<td>31 (*10)</td>
</tr>
</tbody>
</table>
Intervention and Data

The students in 2nd grade received a different engineering curriculum than did the students in 3rd, 4th, and 5th grades. However, all of the students received instruction on the same engineering principles, including design, problem solving, critical thinking, and working with constraints. Students were engaged in several projects, including designing a wallet or a cup holder using a limited amount of materials, developing effective windmill blade systems, creating detailed procedures for problem solving, and designing toys using a catapult inspirations. Students were introduced to the design process using a hands-on activity where they created a prototype of a table. The Affinity students met as a multi-age group for two additional engineering classes each week. On the final day of engineering class, each of the students in grades two, three, four, and five completed a context map. The students were given a 13” x 20” sheet of paper and were asked to write the word, "engineering" in the middle of the paper. They were then given a short lesson on context maps by being provided with an example context map created using the concept of "school." After the short lesson, students were given 40 minutes to complete their context maps. They were permitted to utilize their engineering journals (used during the instructional time) and dictionaries, but were not permitted to discuss ideas with their classmates. They were encouraged to write anything they knew or found meaningful about engineering. The following analysis is based on their context maps.

Analysis

The context map data were analysed using a coding system developed using the five types of meaning incorporated in the Contexts of Meaning Framework (i.e., Semantic Knowledge, Personal Experiences, Metaphors, Interpretive Frameworks, and Emotions-Values-Aesthetics). In addition to these five types of meaning, a sixth was added for the purposes of this study: Misinformation. This category was needed in order to capture student responses that appeared to indicate a misconception or a misinterpretation of information. Every entry on each context map was coded according to the six categories. Though not a necessary component of the Contexts of Meaning Framework, for this study, each entry received one code.

A secondary coding system was used to better understand the nuances of student responses. This coding system, developed by Bloom (1992) included three categories: Categorizing, Elaboration/Story-Telling, and Associating/Inferring. Each of these subcategories is further explained in Table 2. Associating and Inferring are explained separately in the coding system descriptions, however, due to the similar nature of these two categories, the context maps were coded using a combined code of “A/I”.

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A confirmatory inter-rater reliability (IRR) procedure was used to validate the secondary coding system. Due to the action research nature of the primary coding system, only one coder (the facilitator of the intervention) coded the responses. To validate the secondary coding system, the first coder (the facilitator) coded the student responses. All Semantic, Personal, and Emotions-Values-Aesthetics responses were given secondary codes in order to gain deeper insights into these responses. A second coder then coded the responses to check for agreement and disagreement with the first coder. This round of coding prompted a discussion and several modifications/clarifications to the coding system. A second round of coding (n=9 maps) revealed a 100% IRR. After an adequate IRR was established, the first coder coded the remaining 51 maps using the secondary coding system.

**Results**

To answer the first research question, "What engineering meaning, based on the Contexts of Meaning framework, emerged from the students’ context maps after the engineering intervention?" the responses were compiled according to each of the Contexts of Meaning categories. Table 3 provides information about the context map responses. Note: No Metaphor responses emerged from the students' context maps, so this category is not
evident in the table. Additionally, Interpretive Frameworks will be discussed at a later point in the paper.

Table 3: Average Number of Context Map Responses for Primary Coding

<table>
<thead>
<tr>
<th>Grade Level</th>
<th>Semantic (n=902)</th>
<th>Personal (n=1078)</th>
<th>Misinformation (n=25)</th>
<th>Emotions, Values, Aesthetics (n=41)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>15.03</td>
<td>17.97</td>
<td>0.42</td>
<td>0.68</td>
</tr>
<tr>
<td>2\textsuperscript{nd}</td>
<td>7.25</td>
<td>13.94</td>
<td>0.06</td>
<td>0.81</td>
</tr>
<tr>
<td>3\textsuperscript{rd}</td>
<td>21.47</td>
<td>12.60</td>
<td>0.60</td>
<td>0.67</td>
</tr>
<tr>
<td>4\textsuperscript{th}</td>
<td>20.33</td>
<td>22.93</td>
<td>0.73</td>
<td>1.07</td>
</tr>
<tr>
<td>5\textsuperscript{th}</td>
<td>11.36</td>
<td>23.00</td>
<td>0.29</td>
<td>0.14</td>
</tr>
</tbody>
</table>

From the context map responses, it is evident that students created more personal experience responses than semantic knowledge responses. This provides evidence that students were able to draw their own conclusions, make comparisons, elaborate on what they learned and experienced, and formulate their own interpretations about engineering. Third grade students, taken as a group, were the only students who responded with a greater number of semantic knowledge (average of 21.47 responses per student) rather than personal experience (average of 12.60 responses per student) responses. Though all grade levels had some level of misinformation present in their maps, this level was low, with the greatest number being 0.73 average responses in fourth grade. The emotions-values-aesthetics category also had few responses, with the greatest being 1.07 average responses in fourth grade. This can be interpreted to mean that students were not recording many emotional or value-laden statements on their maps. An example of a fourth grade female student’s context map is presented in figure one.
The student context map (Figure 1) represented both semantic knowledge and personal experiences. The words, “Ask, Imagine, Plan, Create, Test, Improve” were all considered to be semantic knowledge since they are the steps of the engineering design process (Cunningham, 2009) and this information was formally taught during the engineering class. The remaining words all represented personal experiences with engineering. Phrases like “what is the design” provided an indication of what the student thought about when approaching a design task, and words such as “decide” and “communicate” told a story about this student’s experience with teamwork during the design process.

The second research question, “How did the students’ expressed engineering meaning relate to the engineering intervention objectives” was best answered by examining the interpretive frameworks the students used to create their context maps. Four interpretive frameworks emerged from the students’ context maps: General Engineering (GE), Engineering Design (ED), Class Projects (CP), and Engineering Design Process (EDP). Some students expressed two interpretive frameworks (e.g., EDPGE). The interpretive framework frequencies are presented in Table 4.

<table>
<thead>
<tr>
<th>Interpretive Framework</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>12</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>ED</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>CP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>EDP</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>EDP-GE</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>EDP-ED</td>
<td>0</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>EDP-CP</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>GE-ED</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>CP-GE</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Overall, the most common interpretive framework was General Engineering. When students used a General Engineering interpretive framework, they included several different ideas about many aspects of engineering, however, they did not go into great depth (i.e., at least three ideas with an additional 2+ ideas extending from each of the three ideas) on any one engineering facet. Many students also used the interpretive framework of engineering disciplines, meaning they focused the content of their context maps on the various types of engineers (e.g., Civil, Environmental, Electrical). Students who used the interpretive framework of Class Projects focused primarily on the activities completed during engineering class. Finally, those students who chose to use the engineering design process as their interpretive framework organized their context maps around the steps of the design process. The student whose context map is featured in Figure 1 used this interpretive framework. The objectives of the engineering intervention were to help students become more engineering literate by providing opportunities for engineering
design, problem solving, critical thinking, and working with constraints. The interpretive frameworks expressed by the students indicate that they are able to communicate about many different facets of engineering, including the design process, the many different types of engineers (who they are, what they produce, their role in society), the different engineering activities completed in class, and different aspects of engineering.

When considering the process question, “How useful were context maps to detect students’ meaning associated with engineering?” we look to Tables 3 and 4. The context maps, using the Contexts of Meaning coding system provided a tool for detecting and interpreting students’ meaning associated with engineering. However, in order to gain a more nuanced understanding of student meaning, a secondary coding system needed to be developed and utilized in coding the responses. In his 1992 study, Bloom provided three sub-codes that could be used for secondary coding: Categorizing, Elaborating/Story-telling, and Associating/Inferring (see Tables 2 and 5). Adding these three codes to the personal experiences, metaphors, misinformation, and emotions-values-aesthetics categories provided a richer picture of student meaning and knowledge about engineering.

Table 5: Secondary Coding Response Counts and Percentages

<table>
<thead>
<tr>
<th>Grade Level</th>
<th>Gender/ Affinity</th>
<th>Categorizing</th>
<th>Elaboration/ Story-telling</th>
<th>Associating/ Inferring</th>
<th>Total Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Male</td>
<td>58 (.33)</td>
<td>36 (.21)</td>
<td>81 (.46)</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>73 (.33)</td>
<td>29 (.13)</td>
<td>122 (.54)</td>
<td>224</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
<td>58 (.25)</td>
<td>96 (.41)</td>
<td>82 (.35)</td>
<td>236</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>78 (.27)</td>
<td>101 (.35)</td>
<td>109 (.38)</td>
<td>288</td>
</tr>
<tr>
<td></td>
<td>Affinity</td>
<td>56 (.29)</td>
<td>60 (.31)</td>
<td>79 (.41)</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>Non-Affinity</td>
<td>80 (.24)</td>
<td>137 (.42)</td>
<td>112 (.34)</td>
<td>329</td>
</tr>
<tr>
<td>4</td>
<td>Male</td>
<td>57 (.18)</td>
<td>156 (.49)</td>
<td>106 (.33)</td>
<td>319</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>48 (.14)</td>
<td>118 (.34)</td>
<td>181 (.52)</td>
<td>347</td>
</tr>
<tr>
<td></td>
<td>Affinity</td>
<td>26 (.13)</td>
<td>82 (.42)</td>
<td>89 (.45)</td>
<td>197</td>
</tr>
<tr>
<td></td>
<td>Non-Affinity</td>
<td>79 (.17)</td>
<td>142 (.30)</td>
<td>248 (.53)</td>
<td>469</td>
</tr>
<tr>
<td>5</td>
<td>Male</td>
<td>43 (.15)</td>
<td>51 (.18)</td>
<td>186 (.66)</td>
<td>280</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>47 (.23)</td>
<td>30 (.15)</td>
<td>125 (.62)</td>
<td>202</td>
</tr>
<tr>
<td></td>
<td>Affinity</td>
<td>35 (.18)</td>
<td>34 (.17)</td>
<td>129 (.65)</td>
<td>198</td>
</tr>
<tr>
<td></td>
<td>Non-Affinity</td>
<td>55 (.19)</td>
<td>47 (.17)</td>
<td>182 (.64)</td>
<td>284</td>
</tr>
</tbody>
</table>

Table 5 provides detailed information about secondary codes that emerged from student context maps.
Interestingly, when reviewing the percentage of responses per subcategory, there were only small differences between the male and female students, as well as small differences between the Affinity and Non-Affinity students.

Discussion

Several important points emerged from the context map assessment. The first is that in three out of four grades, the average Personal responses were greater than the average Semantic responses. This reflects the notion that students, after the engineering intervention, were making their own meaning and drawing their own conclusions about engineering rather than just reproducing the information formally presented during class. Few students provided Emotions/Values/Aesthetics responses. There are many possible explanations for this occurrence, however, one reason could be that students felt the assignment lent itself primarily to recording factual information, not opinions and feelings about engineering.

Another interesting point was that there were not large differences in the secondary code responses between male and female students. This is an important phenomenon because often, in the case of engineering, female students achieve less than male students (Ohland, Brawner, Camacho, Layton, Long, Lord, & Wasburn, 2011; Cano, Kimmel, Koppel, & Muldrow, 2001; Crawford, Wood, Fowler, & Norrell, 1994). In this case, the two groups scored very similarly. This could mean that a context map assessment is a less gender-biased assessment than other engineering assessments currently being used. The fact that there were not large differences between the Affinity and Non-Affinity students is also interesting to note. Further research could help to understand and to explain why these two groups performed so similarly.

Conclusions and Recommendations

Future research plans include further developing the secondary coding system to gain a deeper and richer understanding of what students found meaningful and what knowledge they portrayed in their context maps. A more refined coding system that allows for differentiation between Associating and Inferring codes is needed.

Additionally, further research into the gender differences, and additionally research into the Affinity and Non-Affinity differences will be necessary to better understand how these two groups conceptualize engineering. Future research will utilize power analysis and statistical tests to determine if meaningful and significant differences actually exist between the groups of students. Finally, interviewing students about their context maps could provide validity evidence for the coding system.

Finally, research into student interest in engineering is called for. Since the intention of early engineering interventions is to help dispel misconceptions about the engineering profession and to raise interest and literacy in engineering, an assessment aimed at gathering this information would be beneficial. The context map study is part of a larger study, and in time, additional data will be analysed to help provide a more complete understanding of student conceptions about engineering.
Context maps are one tool that can be used to help assess student knowledge before, during, or after an engineering intervention. They provide for free expression of student ideas, allowing educators to gain a deep understanding of what students find meaningful. Context maps are different from the traditional paper and pencil exams, which rarely allow for student creativity and flow of ideas and concepts. Using the Contexts of Meaning coding system in conjunction with a context map assessment can provide useful information to educators about what and how students are learning, thus allowing educators to modify their curriculum to best meet the needs of their students.

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Conceptual Change in Precollege Engineering

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Abstract: Conceptual change is the process where an individual’s understanding of a particular process or phenomenon changes to a more sophisticated, accurate, or expertlike understanding of the same phenomenon. Although well utilized in the learning sciences, conceptual change has not been used as a theoretical framework for engineering education research. This paper provides an overview of conceptual change theories for the engineering education research community. These theories can be broadly divided into either revolutionary or evolutionary approaches to conceptual change. An overview of these two categories is provided, along with the differences in how they address various aspects of conceptual change theory. The paper concludes with a theoretical exploration of the relevance of these theories to precollege engineering education.

Introduction

Conceptual change is the process where an individual's understanding of a particular process or phenomenon changes to a more sophisticated, accurate, or expert understanding of the same phenomenon. Conceptual change is one of the most used theories in the learning sciences. Although well researched in the natural sciences, especially physics, conceptual change has not been commonly utilized as a theoretical framework for engineering education research, particularly for understanding engineering learning at the K-12 level. While searching for published material on conceptual change and engineering, one is most likely to find articles that either (a) assess the effect of engineering on science concepts (for example, see Schnittka & Bell’s, 2011 article Engineering Design and Conceptual Change in Science: Addressing thermal energy and heat transfer in eighth grade) or (b) articles, which describe exclusively the scientific aspects of engineering (for example, see: Krause, Kelly, Tasooji, Corkins, Baker, & Purzer’s, (2010) Effect of pedagogy on conceptual change in an introductory materials science course”). It is puzzling, why there seem to be no clearly developed unique concepts in the domain of engineering. It might be partially explained by engineering being commonly defined as the practical application of science and math and so other conceptual domains might not be seen necessary. Still, the fact that the conceptual basis of engineering seems to be entirely borrowed from other domains requires further investigation. The purpose of this paper is twofold: (1) to provide an introduction into the different models of conceptual change and (2) assess the usefulness and adequacy of different models in order
to explain learning and understanding of engineering in K-12. The broader goal is to contribute to a discussion on the conceptual basis of engineering.

Models of Conceptual Change

Models of conceptual change can be differentiated by the answers they provide to several key questions: (1) How is change happening? Models of conceptual change tend to take either a revolutionary approach to conceptual change where change is seen as happening extremely quickly in response to anomalous data or cognitive dissonance, or an evolutionary approach where change is seen as something that happens gradually over time (Vosniadou, 2008). (2) What is changing? The literature distinguishes between granular and individual concepts to entire systems of concepts, so called mental models (diSessa & Sherrin, 1998). (3) How stable are conceptual understandings? Different models either argue that students carry a stable understanding, which expands or will be revised over time or argue that conceptual understanding is the ad-hoc assembly of fragmented concepts dependent on the given context (Özdemir & Clark, 2007). (4) How do people react to data which contradict or challenge their conceptual understanding? The literature distinguishes between ignoring anomalous data, rejection, domain exclusion, abeyance, reinterpretation, peripheral change, assimilation and theory change (Chinn & Brewer, 1993). Affective variables like motivations and engagement can also influence how students will react to attempts to modify their conceptual understandings.

To assess how applicable existing frameworks of conceptual change are for the context of K-12, this paper maps the conceptual space of engineering within the larger science, math and technology concepts. To exist in a physical world requires an intuitive understanding of physics with accompanying naïve theories; engineering does not typically make the same demands as one can navigate the engineered world without generating theories about how it came to be. Although numerous stereotypes exist related to the nature and practice of engineering, the general lack of strongly grounded alternative conceptions or misconceptions about engineering and its processes limit the applicability of revolutionary models of conceptual change to K-12 engineering education. Evolutionary models, in particular diSessa’s Knowledge-in-Pieces model (diSessa, 1993) and both Script theory (Rumelhart, 1980) and Schema theory (Schank & Abelson, 1975), show much greater potential for explaining engineering thinking at the K-12 level. Rather than conceptualizing engineering as a specific knowledge domain, these theories can help to understand engineering as a meta-organizer, helping students to build and reorder connections among existing scientific and mathematic concepts, and strengthening conceptions in this domain. Implications for the introducing of engineering in K-12 will be described in the paper.

How is change happening?

Research on conceptual change originated in the domain of science guided by Thomas Kuhn’s (1996) seminal work, The Structure of Scientific Revolutions, originally published in 1962. Kuhn theorized that most science consisted of normal science which contributed...
to the gradual expansion of scientific knowledge. As scientists perform normal science, they generate data that cannot be adequately explained with current scientific theory. Scientists then begin to develop alternative theories, and when enough data support a particular alternative theory, a paradigm shift or scientific revolution occurs where the scientific community rejects the current theory in favour of the alternative theory and its better explanation and generative potential.

Posner, Strike, Hewson, & Gertzog (1982) took Kuhn’s model of scientific revolutions and applied it to understanding how students’ conceptions of scientific phenomena change in the classroom. They posited four criteria that would lead students to reject their naïve conception of a phenomenon in favour of a more scientific conception. The students need to be dissatisfied with their current conception due to its inability to adequately explain the phenomenon. They need a new conception that is intelligible given their background knowledge to replace the naïve conception. The new conception needs to be plausible. Finally, the new conception needs to be fruitful and lead to increased understanding of related phenomena or guide their inquiry into these phenomena. Educators facilitate these revolutionary shifts through instruction that creates cognitive dissonance.

Chi, Slotta, & De Leeuw (1994) also suggest that conceptual change occurs in a revolutionary manner. They suggest that students’ categorize their scientific concepts, and that groups of concepts are arranged in ontological categories. They postulate three primary ontological categories of scientific concepts: matter, processes, and mental states. Conceptual change that involves rearranging concepts within a particular ontological category is not difficult for the learner. For example, it is not especially difficult to understand that people and dogs are parts of the larger concept of mammals or animals. However, conceptual change that involves moving concepts from one ontological category to another can be difficult. For example, many students believe that electrons in a circuit are matter that behaves similarly to the matter that they observe around them, when to understand a circuit it typically makes more sense to understand electrons as a process of flow. Like Posner et al. (1982), Chi et al. (1994) suggests that these changes in categorization are revolutionary and occur as a result of experiences and instruction.

In contrast to revolutionary models of conceptual change, evolutionary models suggest that change occurs gradually as a result of numerous experiences. Current research suggests that this is a more realistic time scale for conceptual change regardless of how one understands conceptual change (Özdemir & Clark, 2007).

What is changing?

How one understands the term “concept” is a critical component of conceptual change research (diSessa & Sherin, 1998). Jonassen (2006) presents three similarity views of concepts, concepts that are constructed through recognizing similarities in essential characteristics, properties, or attributes. In the classical-attribute isolation view of concepts, a person has learned a concept when he or she can correctly categorize objects based on a set of attributes. The prototype or probabilistic view of concepts also involves categorization, but based on a looser, probabilistic understanding of defining characteristics as opposed to strict rules. In the exemplar view of concepts, people learn
concepts by inducing concept descriptions from examples. Similarity views of concepts are limiting because they take concepts out of context and do not account for concepts in use (Jonassen, 2006). Other views of concepts presented by Jonassen (2006) include the actional view of concepts, where concepts are ways of dynamically organizing personal experiences. The theory-based view of concepts suggests that people organize concepts based on their epistemological beliefs (Jonassen, 2006).

Models

Vosniadou (2003) suggests that individuals create models of phenomenon based on their experiences with the phenomenon. Individuals build theories (what she describes as naïve physics) which provide a “narrow but nevertheless coherent explanatory framework for conceptualizing the physical world.” Naïve physics can get in the way of students accepting scientific theories due to its coherence, limited but still existent explanatory abilities, and grounding and reinforcement in personal experience. Conceptual change is the process of moving from naïve physics to accepted understandings, and consists of the slow and gradual replacement of the students’ beliefs associated with a particular phenomenon.

Schemata

Rumelhart (1980) describes a schema as a “data structure for representing generic concepts stored in memory.” Schemata represent a prototype theory of meaning; to illustrate this he uses several analogies, comparing a schema to a play, a theory, and a procedure. Schemata are like plays in that they provide a structured environment that allows room for interpretation, and do not contain every detail of a situation. A schema contains both variables which operate with a set of constraints and constants. Schemata are used to interpret a particular event, object or situation. Like a theory, a schema can be used to predict outcomes given a particular set of variables. A schema is comprised of subschemata. Schema can be activated either top-down, when a schema activates subschemata, or bottom-up, when a subschema activates a schema which it belongs to. Schemata support both perception and memory. A schema based system suggests three modes of learning: accretion, tuning, and restructuring. Accretion is the gradual building of knowledge through partial comprehension of new material. Tuning involves modification or evolution of existing schemata through the modification of variable constraints or default values, replacing constant portions of a schema with a variable one, or turning a variable into a constant. Restructuring involves creating new schemata through patterned generation done by creating a new schema by modifying an old one or schema induction where the learner recognizes a schema through repeated exposure in multiple contexts over time.

Anderson (1977) makes two major statements in support of a schema theory of understanding. First, he emphasizes that people do not construct understanding by “selecting a template from a great mental warehouse of templates abstracted from prior experience”, essentially discounting Behaviorist theories of understanding. Constructing understanding must be a more dynamic process that involves constructing interpretations. Second, he suggests that “abstract schemata program individuals to
generate concrete scenarios”. They provide a framework of understanding which the person fills in as a given situation dictates. Anderson supports a dialectical theory of schema (conceptual) change, and suggests that Socratic dialogue is an effective strategy to encourage schema change.

Scripts

Schank & Abelson’s (Schank & Abelson, 1975; Schank & Abelson, 1977) represents a very specific understanding of schemata and builds on the analogy of schemata as being akin to the script of a play. Script theory grew out of early research in artificial intelligence on language processing. The authors believed that knowledge can be described as a sequence of events in a particular context, which they refer to as a script. The following are several examples of scripts presented by Schank & Abelson(1975, pp. 151-152):

"I. John went into the restaurant.
He ordered a hamburger and a coke.
He asked the waitress for the check and left.

II. John went to a restaurant.
He ordered a hamburger.
It was cold when the waitress brought it.
He left her a very small tip.

III. Harriet went to a birthday party.
She put on a green paper hat.
Just when they sat down to eat the cake, a piece of plaster fell from the ceiling onto the table.
She was lucky, because the dust didn’t get all over her hair.

IV. Harriet went to Jack's birthday party.
The cake tasted awful.
Harriet left Jack's mother a very small tip."

Example I represents a typical simple script, in this case a script recognizable as eating at a restaurant. Example II is a restaurant script with a slight, predictable variation. Example III starts out as a typical birthday script, but then transitions to a different script with the falling of the plaster. Example IV starts out as a reasonable birthday script, but the last line does not make sense because prior experience with birthday parties do not suggest that leaving tips is an appropriate activity at a birthday party. This example illustrates how scripts bound conceptions of an experience, and how cues inform the choice of an appropriate script. Goals and context motivate the choice of scripts that an individual will choose to enact in a given situation. Going back to the simple example of the restaurant script, an individual would choose to enact this script if he or she is hungry, near a restaurant, and has the money and time to eat at the restaurant.
Networks of p-prims

diSessa & Sherin (1998) propose a very different model of conceptual change. They propose the phenomenological primitive (p-prim) as the fundamental building block of knowledge. Students construct p-prims from their basic experiences and observations of the world. These p-prims are organized by conceptual networks where students establish loose connections between the p-prims. Through experiences that cultivate appropriate p-prims and build connections, students can move towards understanding phenomena in a more scientific manner.

Each of these models represent slightly different understandings of concepts, with different degrees of relevancy to K-12 engineering that will be explored later in this paper.

How stable are the conceptual understandings?

A critical difference between theories of conceptual change is their assumptions about the coherence and stability of students' understanding. As mentioned earlier, Vosniadou (2003) believes that students' conceptions are theory-like, relatively coherent, and change fairly slowly over time. Although not explicitly addressed, schema and script theory suggest relatively stable understanding built from experiences as well.

diSessa (2008) makes a strong argument against both coherence and stability in understanding. He primarily argues against parsimony, in other words trying to oversimplify or ignore pieces of data in the name of creating an elegant theory. Assuming stability results in losing complexity and depth and nuance of understanding. When assuming a stable model, especially that multiple students share the same incorrect stable model, one loses awareness of how individuals construct understanding of a given phenomenon, and what concepts the individual learner may be struggling with. Assuming a stable model may also suggest that student models have the same level of validity as normative scientific models, that they are well reasoned in their development and generative when applied to new situations. This needs to be counterbalanced with a respect for students' models and ideas. diSessa also argues that there is no way to measure stability or coherence of a student's model, so when researchers describe this they are in fact imposing their own views or biases towards their own theories of conceptual change on the student. Assuming that students possess a stable, incorrect understanding that needs to be replaced with a normative, scientific understanding may make it more difficult to discover and work with the student's fundamental pieces of knowledge or p-prims. Rather than trying to restructure a stable theory through revolutionary or evolutionary conceptual change, instruction should focus on developing the p-prims necessary to build the scientific model and the meta-cognitive awareness to appreciate and verify the validity of the scientific model. Assuming a stable, individual model ignores the social aspect of knowledge and understanding, and presumes an individual independent of both social and experiential context. Finally, assuming than an individual's theories are stable and "science-like" in their nature may also incorrectly lead to the assumption that these theories change in manner consistent with Kuhn's (1996) description of scientific
revolutions, and cognitive conflict will successfully lead students to the scientific theory or understanding of a given phenomena.

**How do people react to anomalous data?**

Anomalous data is data that does not conform to a student's present understanding of a particular phenomenon (Chinn & Brewer, 1993). Educators often assume that presenting a student with anomalous data will result in cognitive conflict that will lead him or her to reject or modify their naïve understanding of a particular phenomenon in favour of an understanding that is more closely aligned with accepted scientific explanations (Posner, Brewer, Strike & Herzog, 1982). However, this is often not the case. An excellent example is students attempting to transition from understanding the Earth as flat to understanding that it is a sphere (Vosniadou, 2003): Students find it difficult to reconcile their classroom instruction which states that the Earth is a sphere with their own experiences which suggest that the Earth is flat. Instead of rejecting the flat earth model, they instead wind up with a dual Earth model where there is one Earth that is a sphere and travels through the solar system, and a different flat Earth that they actually live on. Understandings built on personal experience do not change readily when students are exposed to anomalous data.

Chinn & Brewer (1993) developed a theoretical framework to explain the wide variety of ways that students respond to anomalous data. They identified seven different psychological responses that students may have regarding their naïve theory (call it Theory A) in response to anomalous data that supports a scientific theory (Theory B). Students may simply ignore the anomalous data, and forget about or ignore the data. They may also reject the data, which is similar to ignoring the data except that they can provide a reason for rejecting the data. These reasons could include assuming that there was a methodological error in generating the data, believing that the anomalous data are a fluke due to random variation in the data, or believing that the data are fraudulent. Students may also exclude the data from the domain of Theory A, believing that their theory is not supposed to explain the anomalous data. They may also hold the data in abeyance, acknowledging its validity but believing that their theory will be able to explain the anomalous data in the future. Students can also reinterpret the data so that it fits better with Theory A. Finally, the students actually engage in conceptual change and make peripheral changes to Theory A (weak conceptual change), or accept the data and change Theory A, possibly so that it more closely resembles Theory B (strong conceptual change).

Students’ responses to anomalous data vary due to a variety of factors (Chinn & Brewer, 1993). Several characteristics of students’ prior knowledge have a strong effect on their responses to anomalous data. This includes the entrenchment of their current understanding based on the amount of experience they have with the phenomenon in question. The students’ ontological beliefs about the fundamental categories and properties of the world can be particularly difficult to change because they can support understanding across domains. Their epistemological beliefs about what constitutes knowledge and sound theories can also affect their responses to anomalous data. The students’ background knowledge and familiarity with mathematical, scientific, or other concepts related to the theory in question can also affect how they react to anomalous
data. Characteristics of the alternative theory can also influence how students will respond to anomalous data that supports this alternative theory. An alternative theory must be available, it must be accurate, the scope of the theory must match the data, the theory must be consistent, and should be simple. Finally, the anomalous data itself must be credible, unambiguous so it cannot easily be reinterpreted, and be confirmed by multiple data sources. Students must also be willing to commit to the deep processing necessary to evaluate the anomalous data and potentially modify their understanding. Each of these factors can be addressed through appropriate instructional techniques.

Figure 1: The Cognitive Reconstruction of Knowledge Model (From Dole & Sinatra, 1998)

Another way of understanding students’ responses to anomalous data is the Cognitive Reconstruction of Knowledge Model (CRKM), shown in Figure 1 (Dole & Sinatra, 1998). The model begins with an existing conception. A learner’s willingness to change is based on the strength of this existing conception, its coherence, and the learner’s commitment. The authors identified several motivations that can lead to conceptual change, including dissatisfaction with the concept, personal relevance, social context, and the need for cognition. Conceptual change requires a message with a new, alternative concept that must be comprehensible, coherent, plausible, and rhetorically compelling. If all of these elements line up and the learner is highly engaged, strong conceptual change can occur. If the learner is not engaged, weak conceptual change can occur, and in either case it is also possible that no conceptual change will occur.

An important aspect of Dole & Sinatra’s (1998) model is that it identifies the role of learners’ affective states in determining if conceptual change will occur. They recognize that motivation and engagement play a significant role in how students will respond to attempts to encourage conceptual change. Pintrich, Marx, & Boyle (1993) also reject the
notion of “cold conceptual change” that suggests that conceptual change depends nearly exclusively on students’ prior knowledge and experiences. They suggest, that students’ goals, values, self-efficacy and control beliefs all significantly influence conceptual change.

**Conceptual Change in K-12 Engineering**

Engineering is not a strongly conceptual domain, which limits the applicability of theories of conceptual change that presume stable, theory-like alternative conceptions. Science concepts are different from engineering concepts in terms of necessity: To walk, drive a car, or throw a piece of garbage in a trash can requires an intuitive understanding of mechanics and the physics of motion. To understand medical treatments, care for a child or pet, or procreation requires at least a basic model of biology. Cooking or cleaning requires a basic model of chemistry. Existence forces us to develop basic science conceptions, which become either the naïve theories or p-prims that provide the building blocks or necessitate conceptual change, depending on if one subscribes to a “knowledge in pieces” or “naïve theories” view of conceptual change. If engineering is defined as the process of developing a technology to solve a particular problem, existence does not foster the development of engineer in the same way that it fosters the development of personal scientific theories, thus leaving the K-12 engineering student with fewer alternative conceptions that need to be addressed. One can be a fairly adept user and consumer of technology without an underlying understanding of how that technology was created or why it works. Research on conceptual change in K-12 engineering therefore tends to take the form of studies that focus on understanding students’ misconceptions about the nature and practice of engineering as explored through assessment like the Draw an Engineer test (Cunningham & Lachapelle, 2007).

Script theory shows much greater potential for explaining conceptual change in K-12 engineering. Engineering design has been identified as a critical aspect of K-12 engineering (NAE Committee on K-12 Engineering Education, 2009), and teaching students an engineering design process provides an illustrative example of how scripts can be used to explain engineering. As part of everyday life, most students develop an engineering script to solve problems that involves creating a solution and testing it. This script is repeated until a satisfactory solution is found. This script can be modified to develop a more nuance model of engineering design that brings in factors like customers, constraints due to available resources, and using testing of the design and other sources of data to inform revisions of the design.

Engineering can provide a context for building connection between mathematics and science concepts which can help students to develop a deeper understanding of mathematics and science. Applying mathematics and science concepts to the solution of real world problems can lead to measurable gains in understanding (Schnittka, Bell, & Richards, 2009). Drawing from diSessa’s (1998) model, engineering can serve as the conceptual network that ties together concepts from mathematics and science and encourage the development of broadly applicable engineering habits of mind like optimization and working with constraints.
References


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Forging Futures? Engineering in the Primary School Curriculum

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Abstract: Starting with the research question, “How can the Primary School Curriculum be developed so as to spark Children’s Engineering Imaginations from an early age?” this paper sets out to critically analyse the issues around embedding Engineering in the Primary School Curriculum from the age of 5 years. Findings from an exploratory research project suggest that in order to promote the concept of Engineering Education to potential university students (and in doing so begin to address issues around recruitment / retention within Engineering) there is a real need to excite and engage children with the subject from a young age. Indeed, it may be argued that within today’s digital society, the need to encourage children to engage with Engineering is vital to the future sustainable development of our society. Whilst UK Government policy documents highlight the value of embedding Engineering into the school curriculum there is little or no evidence to suggest that Engineering has been successfully embedded into the elementary level school curriculum. Building on the emergent findings of the first stage of a longitudinal study, this paper concludes by arguing that Engineering could be embedded into the curriculum through innovative pedagogical approaches which contextualise project-based learning experiences within more traditional subjects including science, history, geography, literacy and numeracy.

Introduction

In order to critically examine the issues around embedding Engineering into the Primary School curriculum, Engineering was conceptualized by the researchers as where science meets society (DIUS, 2008). Whilst the demand for highly qualified engineers able to bridge the scientific / social divide, and solve increasingly complex global, national and local problems has never been higher, the Engineering profession in the UK is facing unprecedented difficulties attracting young people (IMechE, 2009; Spinks et al, 2006). Furthermore, the shortages faced by the Profession are augmented by the fact that at university level, Engineering Education is manifest by high attrition rates - with more students ‘dropping out’ of Engineering programmes than any other (RAEng, 2007). Whilst the current position may appear ominous, predictions that the situation will deteriorate markedly over the next 20 to 30 years, mean that unless action is urgently taken, the UK will find itself with insufficient Engineering talent able to maintain and develop future society (RAEng, 2007; Spinks et al, 2006).
Given the situation, the need to increase the numbers of young people entering Engineering Education at university is paramount. Yet when the time comes for young people to select their university course, the fact that the vast majority have had no exposure to Engineering whilst at school is proving to be a major ‘stumbling block’ for those wishing to increase participation in Engineering programmes at university level. In order to address this, the researchers set out to investigate the issues surrounding engaging children in Engineering Education from the age of 5 or 6.

Context: Primary Level Engineering Education in the UK

The importance that Engineering plays in maintaining and developing our society is the subject of much debate (Wilson & Harris, 2004; Smith & Monk, 2005; RAEng, 2010) with the need to promote Engineering to young children from an early age discussed in several UK policy documents (see for example DIUS, 2008; IMechE, 2009). Despite such attention, Engineering Education at school level in the UK tends to be a little ‘ad-hoc’ in nature, generally dependent on individual Engineering advocates [individuals with an interest in Engineering who usually run ‘after school clubs’ for small groups of children]. At primary school age in particular, much current provision tends to be based on a ‘competition model’ – sparking children’s Engineering imaginations by encouraging them to take part in exciting short-term ventures where they are given the opportunity to develop basic Engineering skills by participating in ‘hands on’ learning projects (see for example Primary Engineer, 2011; Imagineering 2011). Whilst this model does much to raise the profile of Engineering, and does indeed enthuse those children who become engaged, not being part of the curriculum means that such provision can only reach a small minority of schools and children. Inevitably, despite all best intentions – the majority of children have no exposure to Engineering whatsoever. Thus, the possibility that by the time they reach 16 or 17 the vast majority of young people have had no real exposure to Engineering represents a significant problem for those responsible for attracting students onto university programmes.

Methodological Approach: An Exploratory Study

Starting with the research question “How can the Primary School Curriculum be developed so as to spark Children’s Engineering Imaginations from an early age?”, the researchers set out to critically analyse the issues surrounding embedded Engineering Education into the primary school curriculum from the age of 5 or 6 years. An approach based upon grounded theory methodology was identified as the most appropriate (Strauss & Corbin, 1998) as it provided a useful set of research strategies with which to undertake social investigation into the experiences of primary school age children (Cummings, 1985).

An exploratory study following a mixed methodological design has been undertaken. This study has involved two distinctive stages. The first of these comprised 20 semi-structured interviews. Utilizing theoretical sampling techniques, the interviews were held over a 12 month period and involved a range of different people including representatives from non-profit organizations responsible for offering or facilitating extra-curricula
Engineering Education projects, representatives from Government bodies, and teachers at primary and secondary level.

Following this, non-participant observations were conducted at a primary school national Engineering Education event held one Saturday in the Spring of 2011. The observations were undertaken utilizing an ‘observational framework’ drawn up using the findings of the interviews / literature. The national Engineering Education event was attended by around 200 primary age children and their teachers / parents [Approximate participant numbers: Children: 200 / Teachers: 120 / Parents: 150: Other interested parties: 35].

It should be noted that the event at which the observations took place was organised by one of the leading non-profit organizations in the UK whose remit is to work with primary schools to encourage and enthuse children about Engineering. There were children, teachers and parents from 100 schools – mostly from the Northern part of England (but with some representation from the Midlands, South East and Wales). All of the teachers had received training and support from the non-profit organization who had organized the event. Many of the children were supported by their parents – some of whom were engineers. Whilst, the value of the support and input given by the non-profit organization to the schools, teachers and children was evident from the onset, both researchers were acutely aware that the schools represented at the event represented only a small minority of the total number of schools in the UK. Sadly, the majority of schools do not engage with any extra-curriculum Engineering Education activities.

A meta-analysis of both stages of the study was undertaken following a grounded theory approach. This involved open coding and axial coding in which the data was theoretically analysed and the relationships between the relevant concepts and sub-concepts critiqued (Strauss & Corbin, 1998). The below paragraphs provide an overview of the findings.

Findings & Discussion

Three main concepts were identified during the analysis of findings, each relevant to primary Engineering Education. These were: pedagogic issues; exposure to Engineering within the curriculum; and children’s interest.

Pedagogic Issues

Half of the people interviewed in the first part of the study were directly involved in providing or facilitating Engineering Education initiatives to UK primary schools, on either a paid or voluntary basis. Six of these had previously been employed as Professional Engineers (four of whom were now ‘retired’), two were previously teachers, and two were academics. All of the other interviewees were primary or secondary school teachers. In all of the interviews, one theme repeatedly mentioned was that of teacher training and, what the majority of participants perceived to be, a lack of confidence amongst teachers in providing practical ‘hands-on’ Engineering activities. Probing by the interviewers into the perceived causes of this identified two distinctive issues: inadequate / insufficient training; and a lack of understanding as to exactly what Engineering is. With regards to the observations of the primary school event, both researchers made observations as to how
committed and enthusiastic the teachers (and parents) were. All teachers spoke enthusiastically about the training and support given to them by the non-profit organization responsible for organizing the event. This theme was echoed throughout the day – giving some indication not only of the high regard that the teachers held for the organization, but also of the pedagogical value that high level training and support could have in promoting Engineering to primary school children. Indeed, many suggested that without the training they would not have had the confidence to embark on such an initiative. Another issue raised by the teachers related to the time that the project had taken them. Already working in a pressurised environment, many commented that for the projects to be sustainable there needed to be an organisational and managerial commitment to supporting the initiative.

In the interviews, a separate pedagogical theme related to the National Curriculum. For the teachers amongst the sample, the restraints placed upon them by the National Curriculum represent a real barrier to the introduction of Engineering Education at both primary and secondary level. Whilst for the interviewees, such constraints inevitably mean that Engineering is a low priority discipline, the observations conducted during ‘real-life / real-time’ activities revealed the ‘added value’ that Engineering can contribute to the National Curriculum. The children at the event had built a vehicle, which they then demonstrated to each other, their teachers and parents, in a competition. Many of these vehicles encapsulated other parts of the curriculum, with historic themes varying from Victorian England, The Second World War and the Vikings; additionally a plethora of different creative artistic themes was evident. All of the children had a written ‘log’ capturing their learning whilst participating in the project. The high levels of thought and input underpinned by literacy, maths and science in these logs was in itself impressive – although the children’s enthusiasm in verbally explaining the underpinnings of their work was even more so. In many cases these logs gave a detailed overview of the considerable research undertaken by the children to underpin the discussions made for the vehicle design and production.

**Exposure to Engineering Education**

All of the interviewees identified a lack of access to Engineering Education as being problematic for children and teachers alike. Whilst non-profit organizations make a point of engaging with as many schools as possible, the reality is that they are severely restricted by a lack of resources. Furthermore, the lack of a single coherent Engineering Education strategy and policy means that the vast majority of primary (and secondary) school pupils do not have access to any Engineering projects whatsoever. It should be noted that Design & Technology (D & T), Science and Maths are on the primary school curriculum. However, it was evident in the interviews that those responsible for teaching felt that the curriculum is too restrictive in that it does not allow for innovation in learning and teaching – and therefore discourages individual teachers from introducing Engineering. Whilst D & T, Science and Maths were acknowledged as being important components of Engineering Education all of the interviewees indicated that without a wider context such subjects generally fail to engage the majority of children. Engineering can add such context. Those who did access Engineering Education by means

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of extra curriculum activities such as afterschool clubs and competitions noted that children who are generally 'turned off' by Science and Maths often engage with Engineering projects, preferring a 'hands on' practical 'real-life' approach to learning. This was evident in the observations, as the children observed hailed from a wide-range of socio-economic and ethnic backgrounds. Notably, there were equal numbers of girls and boys. All of the children, who were aged from 5-11 years, were very keen to show what they had learnt and excitedly explained how their cars were built, tested and powered. Moreover, all expressed a desire that Engineering projects such as those they were exhibiting should be part of 'everyday' school activities and not restricted to afterschool clubs.

In discussing afterschool clubs and Engineering competitions with the interviewees, one repeated theme related to a general concern about the lack of empirical evidence regarding their long term value and impact. There is clearly much room for further investigation in this area. The theoretical sampling techniques utilised in the study, reflective of the methodological need to talk to 'expert-practitioners', and to observe children actually engaged in Engineering Education, meant that all of the participants had an interest in the provision of Engineering Education to schoolchildren. Furthermore, the meta-analysis of the data strongly suggests that exposure to Engineering is vital in sparking children’s Engineering imagination, getting them engaged and interested. Despite this, and despite the good work of the non-profit organizations already involved in this area, it is evident that the vast majority of schoolchildren in the UK receive no exposure to Engineering whatsoever. If future predicted shortages of engineers are to be avoided, this is something that needs to be addressed as a matter of urgency.

Child’s Interest in Engineering & Science

In describing current provision around Engineering Education, the majority of the interviewees expressed concern that because the majority of schoolchildren receive no exposure to Engineering Education whatsoever, they fail to gain any interest in the discipline (it is simply ‘outside’ their day to day understanding). This lack of understanding was also evident in some of the interviewees themselves; those of whom who were employed as teachers tended to focus on the ‘Science’ and ‘Maths’ aspects of Engineering, appearing to have little understanding about what Engineering actually is. Conversely, the behaviours, interactions and communications observed during the Engineering Education event proved that when given the opportunity to engage with Engineering Education projects – children have the ability and enthusiasm not only to participate in the ‘hands on’ aspects of Engineering, but also to learn and begin to understand the basic knowledge underpinning their projects. Likewise, whilst the teachers who had been interviewed during the first stage of the research appeared to have difficulty in seeing Engineering as a distinctive, yet interlinked discipline, those observed in the event appeared to have no such problems. It was evident that many of the teachers
present at the event took the opportunity to contextualise the Engineering project into other aspects of the curriculum. Whilst this appeared on the whole to be successful, informal interviews with the teachers suggested that many are frustrated that such a project was generally labelled ‘extra-curricula’ and as such did not capture all of the children.

For the teachers interviewed, one major concern is the transition between primary and secondary education. This was identified as being manifested by a decline in interest in science education. Given the perceived drop in interest in science between primary and secondary education, the need to spark children’s interest in Engineering during primary education is particularly important. Likewise, the need to extend the children’s exposure to Engineering beyond the project and the competition was raised by many teachers who noted that although the competition had created interest, that interest needed to be sustained and built upon.

**Conceptual Framework**

One major issue faced by the researchers in conducting this study is that with one or two notable exceptions (see for example English et al, 2009), there is a lack of previous empirical investigation in this area. In the UK in particular, the researchers have found themselves on new ground. The lack of previous empirical research in this area, combined with the sporadic nature of the current provision, makes the need to clarify the key conceptual, theoretical and practical groundings of the subject of great importance. In order to provide such clarity a conceptual framework has been developed utilizing the findings of the research thus far. This is displayed in Figure 1.
The somewhat limited nature of primary level Engineering Education in the UK means that prior to conducting further investigation, it is necessary for the researchers to gain a detailed and accurate picture of current provision of primary Engineering Education. The next stage of the research process will be to work closely with the current non-profit providers of primary level Engineering Education to undertake an in-depth mapping and critical analysis of current provision. It should be noted that some evaluation has already been undertaken – the researchers anticipate building on this in a more academically grounded and rigorous manner. Consequently, the above conceptual framework is key to future research as it will provide the means by which the researchers can frame, record and analyse the data. The framework will adjusted and amended as the research findings are analysed and the study develops.

**Conclusions**

This paper has discussed the emergent findings of the first stage of a longitudinal study. The study so far has shown that through innovative learning and teaching approaches Engineering could be embedded into the primary curriculum. Indeed, it is possible that the project-based and hand-on nature of Engineering Education could potentially provide the tools with which teachers are able to contextualise children’s wider learning experiences within more traditional subjects including science, history, geography, literacy and numeracy. An additional component of the work will focus on exploring the international environment, encapsulating the different educational systems across the globe.

In conclusion, this project has begun to provide evidence regarding the potential pedagogical and social value of embedding Engineering into the primary school curriculum. By stimulating children’s Engineering imaginations, we can begin to address the dire warnings about future shortages of engineers. Thus there can be be little argument that this study is important for the future of Engineering in the UK in particular, but also more widely.

**Acknowledgement**

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**References**


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New methodology on Applied Geology and Geology for Engineers education by using practical trip

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Abstract: There has been much discussion on the primacy of theory over practice. Today prevails the exaggeration of practice. This idea forgets too that teaching problem is a problem of right balance. The approach of the action lines on the EUROPEAN HIGHER EDUCATION AREA (EHEA) framework provides for such balance. Applied Geology subject represents the first real contact with the physical environment with the practice profession and works. Besides, the situation of the topic in the first trace of Study Plans for many students implies the link to other subjects and topics of the career.

This work analyses in depth the justification of such practical trips only on Applied Geology. This methodology could be usual in Study Plans of pure sciences career, Geology or Biology, but not in Civil Engineering like teaching method. It shows the criteria and methods of planning and the result which manifests itself in pupils. Therefore, work shows a methodology taking in account the engineering perspective, the practical point of view and the learning process inside students and their evaluation and, hence, their marks.

Introduction

Geology and geomorphology have always had an important role on applied studies in Civil Engineering, which is in the shallow part of the Earth crust where support infrastructure works. It has been from second half of the 20th century where a great development of the applied studies has been reached: natural hazards, water and wind erosion, flooding, landslides, risks linked to the karst and the coast, etc. They also include Geology and climate aspects related to the relief and related to environmental aspects, even anthropogenic and environmental impacts. However, the teaching is applied in the civil engineering career. For example, Bachelor’s degree of Territorial and Civil Engineer relates specifically the study of Climate and Geology jointly and from the point of view of their application. This implies a practical knowledge of Physical Geography. All this complicates the course programme of Applied Geology and teaching activities. The term "Geology applied" is the name of the main subject from which they derive others. It is considering geological matters that are necessary to the engineer for the development of works. The applied nature necessarily implies teaching methods that transfer experimental, engineering and scientific, knowledge at the same time. The Applied
Geology is the application of the principles and methods of Geology to Civil Engineering needs.

**Context and background**

The engineer is required to have the following skills:

1. Engineer must have a sufficient theoretical knowledge so that they can be applied to solve specific problems, the capacity of criterion to simplify these one, and taking into account factors such as speed, simplicity, quality and economy.
2. Engineer must take advantage of pre-existing data, know where they are, how to find them, how to select them and avoiding repetitions.
3. Engineer must get sufficient skills in order to analyze and assess sample of data or results, with regards to reality and, finally, reach a satisfactory resolution.
4. Engineer must find solutions, although they are approximate but always successful.

But Geology has another object. His ultimate goal is the exploration of the history of the geological events through observation, deduction and reasoning and, in exceptional cases by direct underground exploration or experimentation. Experimentation is very limited in Geology; reproduction in the laboratory of certain phenomena or processes geological, among other things is difficult because both the time and space acquire a great magnitude. For this reason, some aspects of the Geology are close to descriptive sciences, whereas others, closer to techniques, such as geophysics and geochemistry, have assimilated advances experienced by the physics and chemistry.

Geology is studied in all about Civil Engineering. We believe that the engineer should have a general but no detailed geological formation. Attention will focus on those aspects of the Geology which are full of particular practical importance to the Civil Engineering: External Geodynamics, Structural Geology, Petrology or Stratigraphy.

**Research questions**

Work shows a new methodology to teach and learn Applied Geology attending particular circumstances mentioned: teamwork, Applied Geology like practical subject, teachers and students.

**The teamwork of the civil engineer**

The engineer has to know how to use the services of specialists, in our case a geologist specialist. And, generally speaking, teamwork: geologist-engineer in coordination. Geologist analyzes the conditions as they are, and the engineer considers the conditions can be changed so that they will serve for a certain purpose, i.e. to overcome the difficulties that the geologist he predicts. Geologists should take into account that what the civil engineer needs not a complete geological survey, but enough information to be sure about terrain expected conditions: lithostratigraphy, plain language, separation of real issues from interpretable ones, etc.
Geologists, engineering geologists and civil engineers have to work as a team. If they ignore each other, there is a permanent risk which has its origin in the different training received. The risk of lack of connection can fill with the degrees of engineering geologist, where in one person met two aspects: geological and engineering. However, these two aspects are real in civil engineers with training and experience in Applied Geology.

**Importance of the practice in Applied Geology**

We could define the Applied Geology like the application of the principles and methods of Geology to the needs of Civil Engineering. It is, therefore, based on geological knowledge. We might call them basic or theoretical. They can be acquired both scientifically and empirically. This knowledge will be transferred like application to the infrastructure works.

A long time, and increasingly, Applied Geology is becoming more important because the works are larger and more complex and have more impact on the ground: tunnels and large works, greater demand for industrial rock, better use of all water resources, including the subways, preponderance of the environmental aspects etc. The new works require greater demands with respect to the knowledge of the terrain (surface and in depth).

On the other hand, the geology perhaps is the part most random and difficult to analyze in projects or in constructions. In infrastructure works, terrain is showed in very different geological processes. The most of the problems and uncertainties lies on this. And their economic consequences may be very significant, like it has been observed in the frequent amendments to projects. The history of large buildings and structures is full of effects of geological origin. Therefore, we must stress the importance of the geology, both basic and applied.

**Students roll**

The teaching of geology and related subjects is adjusted to a curriculum that supports few variations (material limitations and teachers). Also, teaching is adapted to the degree of knowledge of geology that high school students bring. The most part of new students in Escuela de Caminos de Madrid comes from high school. They know poorly Geology. The Geology is an optional subject for those who follow the option for engineering. There are very few who choose it, certainly below the 10%. They prefer Technical Drawing, subject of preparation to the first year in university.

There is another added difficulty, perhaps with secondary order, and it is that by placing the Geology in the initial courses, students still not has got explanations if different types of infrastructures and works. The application of Geology requires each one of them. For this reason, must be taught basic concepts of different projects and their interaction with the terrain.

There are other characteristics of the students who are in initial courses of engineering. They have been taught in an atmosphere of inductive and deductive rigor that predominates on the rote study. Also there is an utilitarian and practical attitude that
elude unnecessary efforts. The geology is for them the first subject of a nature highly qualitative rather than quantitative. Geology does not conform exactly to the frames of mathematical rigour. It is appropriate to insist that the nature and terrain present very changing situations, and with big uncertainties which do not conform to simple geometric models.

**Teachers roll**

Teachers must know the subject and feel it. Having enthusiasm for teaching and research and then, motivate the student and convey the desire to know and love profession. We must always encourage and make pleasant the subject, but also with demand. This is closely related with the professional vocation to geology, to teaching and research, and with the personality of each teacher.

Teachers dedicate many hours to other educational activities, such as the preparation of classes, tutoring, test preparation and its correction, drafting of texts, participation in thesis courts, coordination of courses, etc. The teacher is the primary subject on the programme. He directs its realization (in part, also he runs it) and controls its results. Without the teacher would not be possible teaching as conceived today.

For the exercise of their profession, teachers, must be improved continuously. The improvement becomes from reflection on their experience and progress in pedagogy and science that he teaches. Keep up to date, in this regard, requires, by today, many hours of study and reading. Geology has experienced a spectacular development in recent years. Publishers take to the market translations of general works of this matter and reissues, each year. At only one particular field of geology, the abundance of publications is overwhelming.

As the teaching takes place in an engineering career and not a Faculty of Science, would have to take into account non-decoupling of the professional world, because it would be incomprehensible that we were teaching a discipline in a practical career without parallel experience with the world of business or, at least, know or be aware about methods of the Geology for engineers.

**Pedagogical Principles**

For searching how focus our teaching under these circumstances, it has been designed a teaching experience based on practical trip. This information has been gathered by experience, as said, and by application of pedagogical principles. Years of teaching show us how and when student motivation is higher and how and when knowledge and competences are solid and reliable. We also attend to the very common pedagogical principles which support and explain in some way the collected experience.

As discussed, these facts are set in the beginning:

1. Applied nature of the geology for engineers.
2. Level of knowledge of the student.
3. Degree of participation of the teacher and real experience.
4. Team work and multidisciplinary team.
5. Motivation of the student and the teacher given their profile and their origin.

The pedagogical principles applied are:

1. You learn by doing. Development of a model based on the master and apprentice.
2. Learning in a team. The team goes further in the knowledge that the individual.
3. Student-centred learning. Student is active and not passive within the group. The ability is individual.
4. The student must observe, formulate hypotheses, verify them, execute them and defend their criteria. Competencies are individual.
5. The teacher uses his leadership in a democratic way. He is not authoritarian nor frees the student. He transfers with good sense and ability his knowledge and experience to the student.
6. Knowledge has value by itself. It is not just useful to be evaluated or pass an exam, but the interest of knowledge lies in the professional interest, in the power to do, and in the pleasure.

**Methodology Framework**

Trying to summarize and clarify the used methodology in the real practical trip framework, this methodology is based on the following application of pedagogical situations and objectives. The following table shows methods according to the educational objectives and pedagogical situations required under teaching of engineering environment. This methodology would be applied during practical trip. It was showed under programme framework. It was developed by the authors based on their experience and on mentioned pedagogical principles.

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Pedagogical situation</th>
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<tbody>
<tr>
<td></td>
<td>Knowledge</td>
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<tr>
<td>To know</td>
<td>Theory before visits works on site and places</td>
</tr>
<tr>
<td>To know how</td>
<td>Practical work showed and taught on site</td>
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<tr>
<td>Way to do</td>
<td>n.a.</td>
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<tr>
<td>Attitude</td>
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*Figure 1: Statement of pedagogical situation for practical trips*
Discussion

At this point, it is showed our new proposed methodology which has been applied for last ten years. Every year it was improved adapting variable circumstances (teachers and students) through the preparation and design of the trip.

The choice of itinerary, works to visit, teachers and the geology are important. Before set these variables teacher must be programme stops during trip, cities and places to visit, works under construction, important geological places and points to visit, etc. This programme should be including: dates, times, places in order to facilitate logistic and supporting.

Programme is including proposed learning targets. These ones are included in the course of Applied Geology at Escuela de Caminos de Madrid. In example:

1. Learn main types of minerals and rocks, their identification and training, as well as the processes that affect the rocks: tectonics, weathering and erosion.
2. Know the properties of the soil and rocks on the basis of their origin.
3. Management of geological concepts, with ease and skill that reveal the importance of the interaction of the geological environment with infrastructures works in its feasibility, design, construction and operation phases.
4. Predict and reason behaviours and responses of the terrain and works in their interaction.
5. Analyze geological for every type of civil work conditions.
6. Develop a sufficient confidence in the concepts acquired in the course to link with the rest of the subjects of subsequent courses of a purely technical nature, understanding conditions technicians that can bring the knowledge of the geological characteristics of the environment.
7. Understand and reason around of geological reconnaissance in Geology for Civil Engineering.
8. Experimental and realistic understanding of the geological problems in public, mainly Spanish works.

Result is a programme which integrates and gathers: restrictions and conditions, learning objectives, and pedagogical principles. Methodology is showed with these main points of a practical trip programme:

1. Brief Explanations during trip. Using microphone and papers. Its objective is to underline the importance of knowledge and practice to develop later at the works on site and the countryside. Basic theoretical knowledge is presupposed like learned already, however, must be clarified the most difficult concepts. It aimed to the student towards planned goals.
2. Practical classes during the itineraries with their corresponding stops in the teaching and previously established points of interest. Contact the student with the practical aspects of Geology and Applied Geology to infrastructures works is achieved through practical classes in field and on site. They constitute an essential piece in the subject. And theory can not meet it. Also, it leads an attractive
environment that stimulates questions and the dialogue between teacher and student. This is in the interests of the student.

3. Transfer of experience in the visited works and sites of geological interest. The experience on field and on sites, even if minimal, has fundamental importance in all training of a science of nature, such as geology. No course of Geology for the Engineers can be considered complete without well planned field trips, where the student can get in touch with the field and see what is explained in classroom. Visits to works can provide him an insight into relationship between Geology and Civil Engineering.

4. Discussion and analysis around the visited works. The purpose of discussion and analysis is to understand design, construction, operation, problems, solutions, etc. Passage through the course of Geology represents the first real contact with the physical environment, the profession and works for many students. These debates are directed in such way. These debates also illustrate different types of phenomena and generally not very complex geological structures. The intervention of professionals linked to the works built or under construction, and who have been related to geology, is essential.

Learning Results Evaluation

The assessment of their knowledge is delivered through the production of a trip report or statement structured according to the programme of the same trip. For years we were collecting this report and it is part of exams and questions. Part of subject can be asked and evaluated by this mean, as far as, site are part of the real life of civil engineering. Teacher only must adapt the complexity of problems to the friendly and simpler environment. Students can be evaluated better and they recognise it by specific survey (see next point). Marks are significantly better. Over 10% students are failed in questions related with practical trip which is 3 times less than usual questions.

This report is drawn up in team of students. It details the most important conclusions and it should reflect the results of the learning. All of the students show a good enough report. They collect the main ideas and concepts. Graphics and photographs are representative. It is true that learning outcomes are achieved with sufficiency. These learning results are as follows.

1. Knows and understands the Geological Sciences in a sufficiently deep way, mainly in the fields of Geodynamics Internal and External, Mineralogy and Palaeontology, Historical Geology and Climatology.

2. Applies concepts and principles of Geology and Geomorphology and Climate Science to engineering problems.

3. Develops a sufficient confidence in the concepts acquired in the course, to link with the rest of the subjects of subsequent courses of a purely technical nature, understanding technical conditions.
4. Predicts and rationally manages geological constraints that the geological environment imposes on the feasibility, design, construction and operation of infrastructure works, from the interaction of these with terrain.

5. Understands, from a realistic and experimental point of view, the geological problems with regards to infrastructure works, mainly Spanish.

Students Motivation.

Motivation of students is one of the basic pillars to check if practical trip is helping them. Once practical trip experience is developed, we try to know about results and changes on student’s motivation in learning perspective. This is done regardless of the outcome of their knowledge achievements assessed properly.

For this, it has been designed a survey about their motivation after trip. Survey was made by the Unidad Docente de Geología Aplicada of the Departamento de Ingeniería y Morfología del Terreno (Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos, Universidad Politécnica de Madrid). It was completely anonymous. Its objective was to collect the opinion of the student as a key agent of learning and teaching of the subject. It takes place under new teaching/learning criteria approach at the European framework in Higher Education. The results are exceptionally good with 90% of student’s participation and with very high scores in a number of questions as the itineraries, teachers and visited places (range of 4.5 to 4.2 in a 5 points scale). The majority of students are very satisfied (average of 4.5 in a 5 points scale). In general, student's motivation is moderately high (average score over 4.0), the best valued aspects are about learning and teaching.

Conclusions and recommendations

Once analyzed the results of the evaluations and data from the survey can be said that:

- Practical trip is a teaching tool that joins teamwork, the application of geology to the engineering and the transfer of professional experience.
- The results of learning of the Applied Geology are widely achieved by students.
- It is complex to base a full programme of Applied Geology teaching exclusively on practical trips, however, they teach to know for the professional interest rather than for the interest in passing an examination.
- Practical trip links motivation, learning, innovation and teaching.
- Motivation is not only a question of student inside but question of team, professional utility and realistic approach.
- Logistics can largely damage motivation. Balance between itinerary and logistics is required.
- Practical trip needs to be adapted, under EHEA criteria, to Earth Sciences in Engineering.
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Competence Monitoring in Project Teams by using Web based portfolio management systems.

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Abstract: This paper reports a learning experience related to the acquisition of project management competences. Students from three different universities and backgrounds, cooperate in a common project that drives the learning-teaching process. Previous related works on this initiative have already evaluated the goodness of this multidisciplinary, project-based learning approach in the context of a new educative paradigm. Yet the innovative experience has allowed the authors to define a rubric in order to measure specific competences in project management. The study shows the rubric’s main aspects as well as competence acquisition evaluation alternatives, based in the metrics defined. Key indicators and specific reports obtained from data base fields in the web tool will support this work. As a result, new competences can be assessed, such ones like teamwork, problem solving, communication and leadership. Final goal is to provide an overall competence map to the students at the same time they improve their skills.

Introduction

The actual implementation in Spain of the new educational model –established by the Bologna process in the European Higher Education Area (EHEA)– has brought to life a prolific framework of innovative educational initiatives (Ivaniskaya et al., 2002; Schoner et al., 2007).

In this context, an innovative initiative is presented, an experience based on the usage of Web 2.0 tools, a technology that opens doors to new fields for ample user collaboration.
(Moursund, 1999), in the project management learning area. The goal of this experience is to develop a Bologna oriented learning framework for effectively teaching the basics of project management to grade students with no prior experience, and the added difficulty of doing so under a competitive context, as these students are simultaneously attending other course subjects. In order to achieve that goal, an approach that combines theoretical contents, individual applied tasks, usage of software systems and a strategy of project-based learning by doing it is proposed. More specifically, the interest of this experience is to provide basic project management competences by following a monitoring and evaluation approach.

A previous work (Cobo-Benita et al., 2010) already tackled the difficulties of estimating the effort of both students and instructors in a competitive collaborative environment. The present paper focuses on monitoring the aspects related to the management dimension as well as to improve the e-learning capabilities and the global performance of the system. Different time base analyses can be performed by gathering data evidences stored into the software systems. Moreover, the experiences aims to enhance other management competences such as those related to leadership, negotiation and communication.

Next section presents a brief review on related works, followed by the methodology used and the technological aspects involved in the experience. Results section is oriented to describe the rubric design process and finally, last section shows the conclusions obtained up to now in this on-going experience.

**Theoretical Framework**

Problem-Based Learning (PBL), where student's activities are structured around solving open-ended problems, has proved to be an excellent method for developing new forms of competencies (Graff and Kolmos 2003, Kolmos and Kofoed 2002). Project-Based Learning (called here PjBL to distinguish it from the acronym for problem-based learning) follows a similar pedagogic approach than PBL, but its organizing principle is one or more open-ended projects. A PjBL environment enables students to draw upon their prior knowledge and skills, brings a real-world context to the classroom, and reinforces the knowledge acquired by both independent and cooperative group work (Schmidt, 1993).

Research has been focused too on the context that facilitates and supports the motivation and implementation of PjBL (Lam et al., 2010), as well as in the use of the PjBL approach on scientific teaching (Cavanaugh and Dawson, 2010). Rashid et al. (2009) proposed a project management approach used in a multilevel scheme by promoting an integrated framework for diffusion on distant learning. The framework is based on an integrated systems-engineering approach in the light of the diffusion of innovation theory utilizing techniques of project management and Blooms-taxonomy.

PjBL is an interesting alternative as well in capstone courses where the innovation comes from the interdisciplinary nature related both to the instructor and to the students (Rhee et al 2010).
Moehr et al. (2004) provided different solutions in the context of distant learning strategies, including valuable discussions. General references on the usage of Web 2.0 software tool for PjBL can be found in Graaff et al. (2003). Mehvar (2010) studied the procedure related to synchronous distant learning. Technological approaches have explored as well the agent-based field for improving the current distant teaching approaches (Bouhadata and Laskri, 2008).

The recent experience conducted presents some significant differences from the aforementioned works, resulting in an innovative, value added initiative. Firstly, students do not work in a lab-controlled environment, but in other one in which creativity and teamwork is essential to address an open-ended solution. Secondly, the experience is more focused on the project management discipline, rather than the specific problem to solve. Finally, the learning process aims at enhance the acquisition of competences that have been identified as relevant by the practitioners of the field, as remarked by the International Project Management Association (IPMA) (Caupin et al., 2006).

**Methodology**

**Designing the Experience**

The approach followed in the courses of the different universities involved (Technical University of Madrid –UPM–, University of León –ULE– and University of La Rioja –UR–) is structurally similar. The course begins by asking the students to propose the definition and configuration of a solution to the problem to solve. It must be ensured that the situation proposed allows multiple solutions, the need of multicriteria decision making processes, milestones, different technologies and disciplines to be considered, etc. In brief, that it complies with the criteria of the CIFTER model (GAPPS, 2006) to evaluate the complexity of a project.

The project manager (PM) has the responsibility of organizing the work and leading the team. It is chosen after estimating the leadership features of the candidates by means of the Blake and Mutton test, the negotiating skills by using the NEGO test and the negotiating style by using the DECTI test.

The results of their personal tests are provided to the students so that they can choose their best PM at the kick off meeting according to their initial skills.

Once the PM is chosen, he must define the work breakdown structure (WBS) and negotiate with the other teams –the contractors– their participation according to the scope that it is being defined. The PM also assigns the different tasks to the rest of the members. The performance of the team is monitored on a weekly basis through the software-based support system. The minutes of the meetings and the evaluation of the team members made by the PM are supervised as well.

The instructors support the students’ teams playing a role of technical, management and IT consultants, facilitating a smooth process workflow during the course as well as regular analysis based on performance and learning progress.
At the end of the course, a presentation is required in order to show the results to the client, namely the instructor. The most relevant aspects of the experience have to be remarked, especially the project’s main strengths and the most important conclusions obtained by the team, related to the development of the experience itself.

**Selecting the software platform**

Regarding the selection of the most appropriate web tool, main objective was to provide to the students with the best common platform for ease the collaboration, communication and interaction among them. Many parameters were carefully analysed such as the number of collaborative tools provided (blogs, wikis, forums, automatic e-mail reports, document repository, etc.), the possibility of a real-time supervision of the work, performance logs, security management, roles and permissions, usage flexibility, multiple business capability in the same application, simultaneous management of multiple projects, etc.

According to these parameters, the software environment selected was Project.net (http://www.project.net). This software facilitates the students the use of the different roles that coexist in the management of a project, enabling the team members to communicate and work together even though they might be located at distant locations.

**Implementing the experience**

Within the web platform environment, each company or group of students must generate its own project and must define the tasks to work on, as well as assign resources, define task durations, so that the total length should be equal to the time available for each student.

The collaborative tools provided by Project.net have been used as follows:

- Wiki: knowledge database.
- Blog: where team members have access to record activities performed or tasks completed.
- Documents: repository of documents with a versatile document management system.
- Discussion groups: used as a communication channel, allowing the team members to consolidate ideas, points of view, and thoughts as well as to share their questions with other team members.
- Automatic e-mail notification for a quick transmission of the information to the whole team.

As PM work concerns, a global view of the project is shown at any time in project.net just in one screen, allowing him to check the key performance information on the status of the project, i.e. resource load, scheduled tasks, meetings and so on. This also helps PM to focusing on specific problems, if required.

Regarding the rest of the team members, each student should report, using the software-based support system, the time dedicated to each task, giving as a result the total number
of hours the student dedicated to this experience. This provides a log of the progress made and the time consumption for every task.

A number of classical tools (Work Breakdown Structure, Gantt chart, resource assignment), for planning and monitoring the project are available as well, in order to support the PM decisions management systems.

Indeed, instructors are able to get relevant information from the system, on a comparative basis, which permits a continuous evaluation of each specific project and student.

Competence Model

The framework used as a reference for competences was the IPMA Competence Baseline (ICB) (Caupin et al., 2006). This is the common framework document that all IPMA Member Associations and Certification Bodies abide by to ensure that consistent and harmonized standards are applied. In order to meet the needs of those interested in the practical application of the ICB, the certification process is described for each level, together with a taxonomy and a self-assessment sheet. Professional project management is broken down into 46 competence elements that cover the following aspects:

- Technical competences for project managers (20 elements)
- Behavioural competences for staff members (15 elements)
- Contextual competences of projects, programmes and portfolios (11 elements).

Sixteen competences will be evaluated as a first step of the initiative. This limitation is due to the short duration of the course, just 4.8 ECTS (European credit transfer system), which imposes restrictions on the dedication of both instructors and students. Platform high potential to access to a great number of key performance indicators, allows the instructors to consider further competence assessment schemes. In any case, the competence model of reference is considered adequate.

Results and further steps

Designing the rubric

The evaluation process aims at considering many different dimensions. It makes use of a rubric oriented to measure the improvement in both the transversal and specific competences. As far as the transversal competences are concerned two different kinds of competences are considered: those related to leadership or the capacity of adaptation to new scenarios –systemic competences–, and those related to the capacity of analysis and synthesis, oral and written communication, information management skills, problem resolution, etc. –instrumental competences–. Amongst the specific competences, those related to the capacity of organizing, planning and controlling the project are considered.

To determine the performance on each of the individuals’ competences, different indicators and achievement levels have been established for every role: defective, acceptable, expected, optimum. The evidences related to these performances are collected by different means (Work Breakdown Structure (WBS), minutes of the meeting, etc.).
Achievement levels reflect a maximum score if all the factors are positively achieved. Competence weight is different for project managers (PM) and team members (TM) (Table 1).

**Further steps**

Based on this first draft of competences rubric, the following step is to contrast it with the recent just finished project team works. By doing this, the instructors will be able to get an overall picture of each student individual performance during the course, not only regarding the technical and theoretical aspects of the subject but the improvement level when considering key personal competences.

Feedback of the experience will be essential in order to improve, adjust and develop future initiatives based on this model. Indeed, auto-evaluation and evaluation between students techniques could be put in practice in order to reinforce other key competences. In this sense, project subject, developed under this new approach, opens a broader field in which innovative experiences can be implemented and assessed.

**Table 1: Competence evaluation rubric**

<table>
<thead>
<tr>
<th>Competencies</th>
<th>PM</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teamwork</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projectnet Check List: documents, discussion forums, blogs, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shows an overall positive attitude to collaborate with other teams or/and members of the group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multidisciplinary work has definitively contributed to project success</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Problem Solving</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) Proposed alternatives are clear, reasonable and adjusted to client's requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Sufficient number of alternatives</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>a) Detailed documentation about the chosen alternative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leadership</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Overall picture about the project and tasks to be developed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Natural authority, respected by TM</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>c) Tasks assigned are specific, measurable and reasonable in time and cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commitment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Positive attitude to other member ideas and critiques</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Communication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Realistic attitude, oriented to problem solving</td>
<td></td>
<td></td>
</tr>
<tr>
<td>i) Continuous search for improvements, main aspects of the project in mind</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>ii) Excellent time administration, according to importance of the issues</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negotiation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Oriented to win-win situations, active defence of personal position, respect others ideas</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Project Objectives &amp; Requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Clear specific objectives and client's needs description (3 indicators)</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>b) Clear task description on WBS and the dictionary (3 indicators)</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Scope &amp; Deliverables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Evaluation at three levels: WBS, Work plan, Project plan (1 indicators)</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Resource Assignment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Human and material resource adequate distribution (3 indicators)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>b) Cost &amp; Finance Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Well structured budget and costs breakdowns, by subprojects, phases and tasks assignments</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Procurement Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Well defined contracts, according to technical specifications (9 indicators)</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Change Management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Adaptation to changes (6 indicators)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Control &amp; Monitoring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Adequate follow-up during the whole process (7 indicators)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Reporting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Quality of information and project documentation (12 indicators)</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

**Conclusions**

The combination of a particular methodology and a specific software tool (Project.net) has successfully resulted in proved useful on the following topics:
• There is a boost in collaborative terms on the group dynamics that allows the team members to put into practice specific competences on the project management field.
• The students are required to adopt an active role, as it is them who must solve the problems that continuously might appear along the project development.
• The student is allowed to develop project management strategies similar to those in a professional environment, and the rest of the team members are able to evaluate the management by means of a continuous supervision. Specific competences for project managers are centric as the IPMA model was selected for designing the methodology.
• The student can work at any distant place and keep contact with the rest of their team members.
• Specific management for virtual teams are used both, for negotiation phase as well as for tracking the evolution of the agreed subproject, including mandatory remarks, etc.

The correct use of the collaborative tools is essential for the success of the experience. The web tool is no longer an e-learning platform but a natural medium with which it is possible to learn, communicate, gain knowledge and share the acquired knowledge in an effective manner.

In spite of the short length of this course (4.8 European Credit Transfer System or ECTS), its closeness to professional practice allows to improve the competence of the students as well as their empowerment as they produce, usually for the first time, an answer to a complex engineering problem.

This teaching model is in harmony with the strategies defined in the Bologna process to develop the EHEA because it is based on achieving specific knowledge according to the degrees involved, and developing the skills required for performance of professional duties and respond to the work challenges of a globalised society.

In the end, it was possible to develop this experience thanks to the selected software-based support system and its functionality, including the traceability for all the decisions, actions, documents and discussions.

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GLOBAL ALLIANCE FOR PROJECT PERFORMANCE STANDARDS (GAPPS), 2006. A Framework for Performance Based Competency Standards for Global Level 1 and 2 Project Managers.


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Toward Lifelong Learning: Self-Regulation in Undergraduate Engineering Courses

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Abstract: ABET calls on engineering educators to help students become lifelong learners, and challenges educators to demonstrate their effectiveness at doing so. Alumni surveys are typically used to measure lifelong learning; however, alumni surveys don’t provide information on which learning experiences lead to the development of the strategic skills demonstrated by lifelong learners. Educators need a more nuanced understanding of the effects of specific classroom designs and practices on the process of lifelong learning skill development to better gauge their effectiveness at promoting such skills. The present study attempts to characterize the attitudes and skills of developing
lifelong learners in problem-based and project-based undergraduate engineering classrooms. In order to do this, we propose that characteristics of lifelong learners are approximated best in the context of the formal classroom by characteristics associated with self-regulated learning.

Context

Undergraduate engineering educators have the dual charge of educating students in the content domain of their respective engineering field and helping them to develop the habits of mind that are consistent with those of lifelong learners. To develop the latter instructors must understand which habits are called forth and become part of a student’s repertoire under different instructional conditions. This study is a first look at which behaviours and attitudes associated with self-regulated learners emerge in different instructional environments. We make the assumption that characteristics of lifelong learners are approximated best in the context of the formal classroom by characteristics associated with self-regulated learning.

Research questions

This investigation sought to answer the following questions: What do instructors in problem and project-based environments do to facilitate the development of self-regulated learners? Can instructor practices and behaviours be described that lead to greater student regulation of their own learning? What are students’ cognitive, behavioural, and affective responses to the different ways instructors support their developing autonomy?

Theoretical framework

The present study leverages self-regulated learning theory (SRL) and self-determination theory (SDT) as the theoretical frameworks. Zimmerman (2000) defines SRL as “…self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals” (p. 14). Pintrich (2004) provides four assumptions of SRL models. These are that self-regulated learners (a) are active participants in learning, constructing meaning from information available in the environment in combination with what they already know, (b) can control and regulate aspects of their thinking, motivation, and behaviour and in some instances their environment, (c) compare progress toward a goal against some criterion, and (d) use self-regulatory mechanisms to mediate between the person, the context, and achievement (pp 387-388). Students can be said to be self-determining when these regulatory processes are self-generated.

In the same way that becoming self-regulated is a process of learning to regulate and assuming responsibility for that regulation, becoming self-determined proceeds along the continuum that ranges from extrinsic motivation (controlled) to intrinsic motivation (autonomous) (Ryan & Deci, 2000). Social contexts interact with individual tendencies to create conditions that facilitate movement along the self-determination continuum toward integration and intrinsic motivation (Deci & Ryan, 2000). Deci and Ryan (2000, p.227)
assert that environments that do not support students' competence, relatedness, and autonomy needs result in poorer outcomes in motivation, performance, and well-being.

Both self-regulation and self-determination theories acknowledge the impact of the environment on the individual as the individual strives toward autonomy. How a student responds may depend on both the instructor's teaching strategies and the student's learning strategies (Vermunt & Vermetten, 2004). Where they complement each other, a state of congruence exists; when they are not compatible, Vermunt and Verloop (1999) describe the outcome as "friction", which itself has two forms—constructive and destructive. Constructive friction occurs when the incompatibility between teaching and learning strategies results in the student learning new approaches to thinking and learning. Destructive friction can occur when teachers take over for students who are employing learning strategies the teacher feels will not lead to a positive outcome or when the students do not have the level of self-regulatory skills that the teacher assumes they have.

Different course designs activate different goal structures, student expectations and student behaviours. We suggest that in order to be lifelong learners, students must first be self-regulated learners developing into self-determined learners. In order for this to occur, students must be supported in and have opportunities for taking control of the learning process. Support and opportunity can come in many forms. This study looks at just two variants of student-centered learning pedagogies.

**Methodology**

A mixed-method triangulation research design was employed where both qualitative and quantitative data were collected during a defined research period and analysed simultaneously. A case study design constituted the qualitative methodology; a non-experimental comparative design defined the quantitative methodology. Sampling of courses was purposeful in that particular courses were chosen on the basis of pedagogy: one required chemical engineering course was taught using a problem-based format (PBL); one elective failure analysis course using a project-based format (PJBL). Both formats are student-centered pedagogies based in constructivist theory (Savery & Duffy, 2001). Critical features of PBL are that students actively engage with authentic tasks that become the vehicles for further learning; students determine what they will need to know and how and where to find it; students constantly monitor their understanding; the use of collaborative teams is integral; and the instructor provides appropriate scaffolding and acts as a mentor who pushes the students to deeper learning through questioning and challenging assumptions (Barron et al., 1998; Savery & Duffy, 1995). Problem-based learning relies on the use of authentic but simulating problems that students, with the appropriate assistance from the teacher, can solve together. There are specific content objectives with each problem. Projects, on the other hand, are ill-defined, complex, and open-ended. Barron, et al. (1998) suggests that problem-based is the scaffold to project-based learning.

Although both courses emphasized team-based problem solving and offered significant opportunities for student-student and instructor-student interactions, the types of
problems, constraints, and learning goals were different in the PBL and PjBL. In the PBL course, the instructor presented students with a set of common problems that were designed to help students develop deep conceptual understanding in specific technical areas. Students were expected to decide what they should know and what they would need to learn in order to solve the problems. The PjBL course emphasized analytical process over specific technical content. The attainment of common knowledge was not a primary goal in this course, and students acquired different technical content depending on their project topic. Student teams designed experiments, identified information resources, and established their own goals, timelines, and strategies specific to the projects they selected.

Convenience sampling was used to enlist students from those enrolled in the two courses described above. Thirty-five undergraduate engineering students and two engineering instructors from two private universities in the northeast region of the United States agreed to participate. Complete data sets were available from twenty-six students. All sixteen students in the chemical engineering course were junior chemical engineering students (4 females, 12 males). Ten students (9 females, 1 male; 3 sophomores, 6 juniors, and 1 senior) from the failure analysis course were in the following fields: mechanical engineering (n = 3), electrical and computer engineering (n = 2), engineering (n = 1), and undeclared (n = 4).

Quantitative data consisted of student responses to the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich, Smith, Garcia, & McKeachie, 1991) and the Learning Climate Questionnaire (LCQ; Deci & Ryan). Students completed on-line versions of the MSLQ, a measure of motivational orientations and use of various learning strategies, at the beginning and end of the semester, and the LCQ, a measure of perceived autonomy support, at the end of the semester. Approximately twenty-six hours of transcribed audio-taped samples of classroom discourse and student team work outside of class provide context for interpreting student survey responses.

Data were analysed using Analysis of Variance (ANOVA) to determine between-group differences on subscales of the MSLQ. Analysis of Covariance (ANCOVA) was used to control for differences present at the beginning of the semester on the subscales, and independent group t-tests were used in cases where the homogeneity of variance assumption was violated. An independent group t-test was used to determine between group differences on the LCQ. Dependent group t-tests were used to determine within-group changes on the MSLQ from the beginning of the semester to the end. Effect sizes are reported as partial $\eta^2$ (interpreted as the amount of variance in the dependent variable accounted for by the independent variable) for ANCOVA and Cohen's d for t-tests (interpreted as difference between the means with 0.2 and lower representing a small effect, 0.3 to 0.7 a medium effect, and 0.8 and above as large).

Between-group differences were investigated to understand if students in the different instructional environments reported differences in behaviours associated with self-regulation and perceptions of instructor support for students’ developing autonomy. Although the two pedagogies are quite similar in format, they use different degrees of ill-defined problems as the starting point for learning.
Therefore, differences in some aspects of self-regulation might be expected. Further, the degree of scaffolding provided and ways instructors encouraged deep learning might have influenced the ways in which students perceived autonomy support from the instructors. Within-group differences were investigated to understand if students’ reported changes in aspects of self-regulation from the beginning of the semester to the end.

**Findings**

Between-group differences were found at the end of the semester on the MSLQ subscales of task value ($F_{1,25}=8.091; p=.009, \eta^2=1.15$), extrinsic goal orientation ($F_{1,25}=7.576; p=.011; \eta^2=2.48$), rehearsal ($F_{1,25}=4.786; p=.039; \eta^2=0.88$), organization ($F_{1,25}=5.844; p=.024; \eta^2=0.97$), and effort regulation ($F_{1,25}=4.879; p=.037; \eta^2=0.175$). Students in the PBL course reported significantly greater motivation regulation in task value and extrinsic goal orientation, and significantly greater cognitive regulation in rehearsal and organization. Students in the PjBL course reported significantly greater cognitive regulation in rehearsal and organization.

Between-group differences were also found on the LCQ ($t_{1,33}=-4.398; p=.000; d=1.45$) with students in the PjBL course reporting significantly higher perceptions of autonomy support from their instructor than students in the PBL course. Dependent group t-tests found within-group differences from beginning to end of semester. Students in the PBL course reported greater motivation regulation in intrinsic goal orientation ($t_{1,15}=-2.527; p=.023; d=.63$); greater cognitive regulation in elaboration ($t_{1,15}=-2.699; p=.016; d=.66$) and organization ($t_{1,15}=-2.748; p=.015; d=.69$); and greater behavioural regulation in peer learning ($t_{1,15}=-2.506; p=.024; d=.63$) and effort regulation ($t_{1,15}=-3.440; p=.004; d=.85$). Students in the PjBL course reported greater behavioural regulation in peer learning ($t_{1,9}=-2.325; p=.045; d=.74$); but lower motivation regulation in task value ($t_{1,9}=5.075; p=.001; d=1.61$).

Tables 1 and 2 provide means and standard deviations for between-group subscale differences and within-group subscale differences, respectively.

### Table 1: Means and Standard Deviations for Significant Between-Group Differences

<table>
<thead>
<tr>
<th>Subscale</th>
<th>PBL</th>
<th>SD</th>
<th>PjBL</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Value</td>
<td>5.65</td>
<td>.81</td>
<td>4.65</td>
<td>.96</td>
</tr>
<tr>
<td>Extrinsic Goal Orientation</td>
<td>5.23</td>
<td>.67</td>
<td>2.83</td>
<td>1.5</td>
</tr>
<tr>
<td>Rehearsal</td>
<td>3.81</td>
<td>1.67</td>
<td>2.45</td>
<td>1.31</td>
</tr>
<tr>
<td>Organization</td>
<td>4.17</td>
<td>1.30</td>
<td>2.83</td>
<td>1.51</td>
</tr>
<tr>
<td>Effort Regulation</td>
<td>5.30</td>
<td>.98</td>
<td>5.33</td>
<td>.95</td>
</tr>
<tr>
<td>Support for Autonomy (LCQ)</td>
<td>4.87</td>
<td>1.38</td>
<td>6.48</td>
<td>.35</td>
</tr>
</tbody>
</table>
Table 2: Means and Standard Deviations for Significant Within-Group Differences

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Pre M(SD)</th>
<th>Post M(SD)</th>
<th>Pre M(SD)</th>
<th>Post M(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic Goal Orientation</td>
<td>4.99(.04)</td>
<td>5.43(.92)</td>
<td>3.51(1.05)</td>
<td>4.17(1.30)</td>
</tr>
<tr>
<td>Organization</td>
<td>4.22(1.02)</td>
<td>4.51(1.08)</td>
<td>4.59(.42)</td>
<td>5.30(.98)</td>
</tr>
<tr>
<td>Elaboration</td>
<td>4.35(.79)</td>
<td>4.85(1.37)</td>
<td>3.87(.55)</td>
<td>4.43(.67)</td>
</tr>
<tr>
<td>Task Value</td>
<td>6.08(.46)</td>
<td>4.65(.96)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions

Several differences were noted both within and between the groups, suggesting that these two pedagogies had differential facilitative effects on students. Consideration must be given when interpreting the findings to the degree to which the students in each course were familiar with the particular style of pedagogy. Students in the PBL course reported that they had not had a course structured in this way before. In fact, in a follow-up a year and a half later with these students, they shared that this course was really the first of three taught by this instructor and that it was the most structured of the three with the third being a senior design course which approximates the PjBL course in this study. Students in the PjBL course, on the other hand, reported that most of their courses are of this nature, perhaps not using problems quite as open or ill-defined as the problems in this course.

Within-group differences. Interestingly, there was only one area, peer learning, with reported increases from pre to post-semester for students in both courses. Such an increase is consistent with expectations. Consistent with the design of PBL environments’ reliance on the collaborative construction of knowledge, each instructor made deliberate use of teams. These instructors created problems for students to work through that necessitated collaborative problem-solving resulting in social construction of knowledge.

Students in the PBL course reported the only other increases in characteristics associated with self-regulation (intrinsic goal orientation, effort regulation, elaboration, and organization). Because this was their first experience with the PBL environment, this may have offered an opportunity for them to engage in? behaviours that are consistent with deeper learning. Perhaps the openness of the course design that allowed students to set work goals and timelines resulted in greater efforts for students to regulate and modulate their own. Increased intrinsic goal orientation is significant in that these students reported an appreciation for the challenges this course provided them, offering them opportunities to embrace their curiosity and to persist toward learning rather than simply for a grade. Because the students in the PjBL course reported that they have many learning opportunities similar to their PjBL course in this study, significant changes in behaviours and attitudes aligned with self-regulation might be more difficult to find. It should be noted that, while not necessarily statistically significant, students in the PjBL course...
reported higher mean scores in these areas at the beginning of the semester than students in the PBL course, perhaps attesting to the hypothesis that these students may have already experienced the positive effects that come with such student-centered environments. The non-significant results may reflect a ceiling effect due to instrumentation characteristics.

An unexpected significantly lower mean score was reported by students in the PjBL for the importance and value they placed on the course from pre to post-semester (task value). We found this unexpected because in the hours of audio-taped class and homework sessions, students appeared highly engaged. One explanation for this finding may be related to the elective aspect of the course. Another might be the focus on projects that might not be entirely relevant to all engineering fields represented in the group of students. However, focus group questioning revealed that the statements in the MSLQ pertaining to “task value” might not have captured the students' experience in the course so their responses might not be a true estimate of the value they placed on the course.

**Between-group differences.** Students in the PBL course reported significantly higher scores in task value, extrinsic motivation, rehearsal, and organization; whereas students in the PjBL course reported significantly higher scores in effort regulation and the amount of perceived autonomy support from the instructor. The differences in self-regulated behaviours might be best explained by considering that PBL provides the scaffold to PjBL (Barron et al., 1998). Students in the two courses started out with different expectations about what they would experience over the coming weeks. For the students in the PBL course, the abrupt transition to the more open format of this pedagogy might have resulted in higher reports for them in these areas. Further, the specific content knowledge outcome expectations of the PBL course might be responsible for higher reported levels in extrinsic motivation and rehearsal. Students in the PjBL course were veterans with regard to open format pedagogies but the fact that this failure analysis course utilized very ill-defined problems may explain the higher levels of effort regulation relative to the students in the PBL course. The perception of greater autonomy support by PjBL students may also be an artefact of familiarity with pedagogical structure. The PBL students experienced for the first time the “sink or swim” feeling that students often report when they are in such non-traditional environments and may not have appreciated the types of support offered by their instructor.

**Recommendations**

Engineering educators should consider the types of learning behaviours and attitudes they would like to help develop within their students and then consider what kinds of pedagogies would be most helpful in getting those results. The results of this study indicate that even though these two pedagogies are often considered similar and may in fact be points along a continuum, students reported different patterns of growth within the courses and across the courses. Students may become accustomed to dealing with ambiguity the more they are exposed to it and our measures of growth will need to be able to gauge development of positive tendencies as a result. However, these findings do suggest that as students are exposed to ill-defined problems in supportive learning
environments they tend to adapt in ways consistent with becoming more self-regulated. Future work includes comparison of two more traditional pedagogical conditions to understand if students report a different constellation of self-regulation behaviours as well as comparing all four conditions.

References


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Session 5: Thursday afternoon

Topic: Curricula 2 – Chair: Dawn Williams

Studying Interdisciplinarity in Engineering Degree Courses: Conceptual and Methodological Issues

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Abstract: The aim of the HELENA project was to test if changing the curriculum towards more interdisciplinarity makes engineering degree courses more attractive to women and changes representations. The aim of this paper is to introduce HELENA methodology, to question “interdisciplinarity” and to provide ideas for future research.

HELENA used pragmatic and provisional concepts based on counting the ECTS after deciding a correspondence between a course heading and the classification into one or more disciplines, and then into the category “traditional” or “pluridisciplinary”. In addition, qualitative case studies provided additional information on curriculum and students perspectives on the issue. The lack of conceptual consistence of such a definition made the counting process very tricky, but it provided a starting point.

From HELENA, we propose to question the concepts of “interdisciplinarity”, “attractiveness” and to re-think engineers’ identity and paths to become engineers.

Introduction

Participation in engineering occupations is a key-issue for European economical and technical development. Some studies indicate that the lack of interdisciplinary subjects in E&T curricula is acting as a foil to potential E&T students, males and females.

The aim of the HELENA project was to question or confirm this statement and to provide indications about how to launch such measures and monitor the obtained results. The study is grounded on empirical research about traditional E&T curriculum in Europe and compares them to selected pilot degree courses, which successfully integrated societal impacts in their engineering and technology degree course, all over Europe.

First, we comment HELENA methodology. Second, from HELENA results, we question the issue of “interdisciplinarity” in engineering curriculum. Third, we provide ideas for future research.
Context

Methodology of HELENA

HELENA hypothesis was that rethinking the engineering curriculum with more interdisciplinarity and better-integrated societal impacts of technology would make engineering studies more attractive for potential students, especially women students.

HELENA used pragmatic and provisional concepts. They should be deepened and improved in further studies. The aim of this paper is to point out conceptual and methodological issues for further studies.

HELENA methodology was based on counting the ECTS after deciding a correspondence between a course heading and the classification into one or more disciplines, and then into the category “traditional” or “pluridisciplinary”. A total of 189 study programmes has been studied in Austria, France, Lithuania, Macedonia, Serbia, Spain and United-Kingdom. 157 study programmes have less than 25% of ECTS in non-engineering subjects, they are qualified as "traditional". 32 have more than 25% of ECTS in non-engineering subjects and are called "interdisciplinary". Study programmes are analysed in the fields of ICT (Austria, France, Macedonia, Serbia and Spain), Civil engineering (France and the UK), Environmental engineering (Lithuania), Mechanical engineering (Lithuania) and Industrial management engineering (Spain).

In addition, qualitative case studies provided additional information on curriculum and students perspectives on the issue. 162 semi-directed interviews were carried out in the same seven countries: 72 interviews with students from "traditional" degree courses, 90 with students from “interdisciplinary” degree courses, 79 with female students et 83 with male students.

Public relation documents have been analysed in all qualitative case studies and confronted to the students perception expressed in the interviews.

HELENA Findings

HELENA wanted to prove that more interdisciplinarity makes engineering degree courses more attractive. In term of result, the outcome of the study is complex:

- Where the content of degree courses is the first criterion to choose, introducing more interdisciplinarity is definitely a successful solution.
- Where the content of degree courses is not the first criterion to choose, it is not. Ranking, prestige, chance, personal projects or stereotypes prevail over interdisciplinarity even if interdisciplinarity attraction reappears inside the curriculum, when students are asking to choose optional courses and majors.

Last important outcome of the study: Interdisciplinarity is attractive if taken seriously by curriculum conceptors, which means it is not only an advertising argument, it is part of a coherent and integrated curriculum. Non-SET subjects are taught with appropriate pedagogy by qualified permanent professors.
Questions about interdisciplinarity

HELENA methodology was a starting point. There was a need for pragmatic and provisional concepts to start somewhere. Anyway, “interdisciplinarity” in HELENA lacks conceptual consistence and highlights crucial issues we must deepen in further studies.

The concept

Where conceptual work was pre-existent and embedded in the description of courses, counting ECTS has been relatively easy. Where there was no pre-existent concept, the lack of conceptual consistence made the counting process very tricky. To be able to count interdisciplinary ECTS supposes a clear definition of “discipline” and some serious thinking on “pluri”, “multi”, “trans” with the articulation of courses in a coherent curriculum. Another issue is the polysemic use of “pluridisciplinary” : in some cases it meant two or more disciplines in one course, in some others non-traditional disciplines (i.e. non-SET disciplines), or “unusual” disciplines in the curriculum.

A sound concept of “interdisciplinarity” would suppose a clear definition “discipline” taking into account the history and the social construction of disciplines. Andrew Abbott (2001) has demonstrated how social sciences disciplines have been constructed in Chaos of Disciplines. The same work has to be done for disciplines taught in engineering schools.

The context

Moreover, disciplinary identities are dependent upon the context: “English” as a foreign language in an engineering school is not the same thing as the same discipline taught to future English teachers. “Mathematics” may be perceived in a different way in contexts where they are considered as a selective discipline and a “rite of passage” and where it is not the case.

Another important issue is the curriculum integration: how discipline are taught and articulated in a coherent curriculum? What do we mean by “inter”, “multi” and “trans” disciplinarity? What is the structure of the curriculum? Who is teaching? What kind of pedagogy is used? In HELENA, students’ interviews provide some information, but the topic should be addressed more systematically.

Last remark, “interdisciplinarity” investigation cannot miss the connection with Nowotny, Scott and Gibbons’s work (2001) on “mode 1” and “mode 2” production of knowledge. If we follow them, the development of interdisciplinarity in engineering curriculum simply means that the curriculum has to catch up with the new ways of producing knowledge. In that case, it is not an option to make engineering more attractive; it is a compulsory change in order to adapt teaching to actual science and technology.

Questions for future research

Gender, disciplines and attractiveness

Many studies try to measure attractiveness; HELENA was one. But the definition of attractiveness is not always very clear. Does it mean a higher proportion of students? Male
and/or female? A higher proportion of female students? A positive appreciation of female students? A better success rate of female students? Compared to what?

HELENA underlined the fact that various criteria to be “attracted” interfere here with interdisciplinarity: prestige and ranking, job perspectives, personal interest. Depending on the context, one overcomes the others. Complex dynamics of attractiveness must be described. Furthermore, correlation does not mean causality. In recent years, many changes have affected the curriculum as the Bologna process and the broader access to university. The impact of them has to be taken into account to understand how pluridisciplinarity affects attractiveness.

Besides the idea of interdisciplinarity, there is a danger of gendering the disciplines: human and social sciences, “soft skills” would be “feminine” and attractive to female students, when engineering and technology would be the “hard” sciences and the “masculine” disciplines. Softening the curriculum would attract women. There is here a high risk of stereotyping! Reasons to introduce interdisciplinarity and to explain why it is attractive towards female students must avoid that kind of explanations.

In terms of policy issues, attractiveness is a priority because policy makers think there are not enough engineers to sustain technological development, then we must increase attractiveness to extend the fishing pool. What happens if the engineering students do something else as a career? The complex paths we have observed suggest that it may be often the case. It leads to re-thinking attractiveness: either as a global attractiveness of studies and careers taking into account the professional context and the reasons to study engineering, or as a complex process where it is admitted that individuals build their own path and mix studies and careers in more than one field. What we have observed about students’ less and less linear paths would be a good reason to move to such a complex picture.

**Re-thinking multiple engineering curricula**

Crossing interdisciplinarity and engineering questions the identity of engineers and emphasizes the fact engineering cultures are not the same from a country to another and even in the same country. Identities differ in terms of specialities: agronomy, architecture, business, “generalist engineer” are part of the engineers identity in some countries, not in all countries. Hierarchy and prestige are obviously another important criteria, but not everywhere. There are countries where engineering is a top choice leading to managerial positions, and countries where engineers are focused on technical and scientific issues. In addition, in a same national context, the culture of a “licensed” engineer is different of the culture of an engineer at master level. There are differences between “University of Applied Sciences” and “University” institutions.

So, beyond those identity issues, HELENA highlighted the structural problems that make engineering degree courses comparisons very tricky at European level. Students’ profiles are different, as their motivations and expectations, so comparison is difficult. Curriculum and pedagogical strategies may be very different in the different contexts.
To have a better idea of students’ motivations or engineering attractiveness at European level, we should define different profiles of engineering education and make comparisons only between comparable profiles.

The same idea should apply to the impact of interdisciplinarity on attractiveness: comparisons should take into account comparable contexts and investigate not only degree courses but also optional courses inside the degree courses. It happens very often that curriculum content has a poor impact on reasons for choosing a degree course because the choice depends mostly on the ranking of the student in the selection process leading to degree courses. But attractiveness of interdisciplinarity may reappear inside the curriculum when students are asked to choose optional courses or specialities.

**Re-thinking the paths to become engineer**

HELENA assumed that degree courses and students’ own paths are linear. In fact, through interviews, we discovered that students’ paths are less and less linear. Possible changes and options are part of the attractiveness of the «offer» and corresponds to students’ «demand» for more flexibility and mobility.

To address this situation of complexity of degree courses curricula and complexity of students’ personal paths, we need to rethink completely our approach. From interviews it is clear that students’ choice for a degree course is part of a complex personal strategy. There are very conscious strategies to make the most of the academic offer, and very erratic ones. Representations play a big role in the process: adding a management degree to an engineering degree is supposed to prevent being stuck in technical jobs or offers better job opportunities.

This trend can be observed at highest level. In France, studying at the École Nationale du Génie Rural des Eaux et des Forêts (ENGREF) after a master degree is reserved to a handful of excellent students from the Ecole Polytechnique and the Ecole Normale Supérieure, two very elitist schools. Among the students who prepare a PhD at ENGREF, half of them decide to make a PhD in Human and Social Sciences or Economics despite the fact all of them come from S&T at highest level. This path leads them to top positions in the national government and later to managerial positions in global companies.

The same trend can be observed at a more modest level at Polytech Orleans, an engineering school at the University of Orleans, where we made interviews for HELENA. Many students were afraid of being trapped in technical jobs and wanted to include management in their training to get access to management positions. In that case, the pluridisciplinary degree course adding business and management to engineering was very attractive to them. It appeared also that some students arrived there after an erratic path, where chance played a big role. Pluridisciplinarity in that case helps them to find some coherence in their path.

If the choice of ENGREF students was based on actual opportunities they have because of the structure of the French administration, the choice of Polytech Orleans students was mostly based on representations they have about management, technology, etc. The role of
representation and their relationship to reality should be studied in depth when studying attractiveness.

To sum-up, we recommend to study various paths to become engineers and to consider the non-linear ones because they are more and more common among students.

**Conclusion**

As a conclusion, crossing interdisciplinarity and engineering, studying how engineering curriculum is changing, leads to question the identity of the next century engineers.

On one hand we can regret that science and technology are at risk to be downgraded as second role disciplines because they are too "hard" and not "attractive" anymore — which is paradoxical when, at the same time, we desperately want good science and technology specialists to sustain our scientific and economic development.

On the other hand, we can re-think engineers not only as Science & Technology specialists but as post-modern "honnêtes hommes", in French, or "Renaissance men", in English: people who are able to deal with technical problems embedded in the social and economical context they belong to. This new identity would corresponds to the "mode 2" production of knowledge we experience now.

Our role is now to study accurately the construction and the impact of pluridisciplinary or transdisciplinary curricula. A deep reflexion on disciplines, on curriculum building including pedagogical issues and curriculum coherence, and on meaningful comparisons across Europe would be crucial to build such curricula. HELENA project was a starting point and emphasized the issues we must investigate.

**References**


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Facilitating intellectual and personal skills development in engineering programmes

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Abstract: Accreditation of engineering programmes now requires evidence of substantial development of professional skills in addition to discipline knowledge. Criteria developed by professional bodies refer to a broad range of professional skills such as teamwork, leadership, communication, self-direction for lifelong learning and ethical awareness. It is argued here that the development of professional skills is synonymous with a growth in intellectual development (Perry, 1999) and reflective judgement (King & Kitchener, 1994). Engineering programmes are in general very good at developing technical knowledge and skills but many students fail to achieve acceptable levels of intellectual development by final year. Student-centred learning, provided through a group-based, project-driven spine throughout the programme, can facilitate a high level of intellectual development and lay a foundation in thinking for professional skills to be developed to the level required by professional bodies. Programme teams should consider measuring and reporting levels of intellectual development as part of quality assurance and accreditation processes.

Introduction

Engineering graduates are under increasing pressure to demonstrate high levels of professional skills. The accreditation criteria of professional bodies such as the Accreditation Board for Engineering and Technology (ABET) in the US, Engineers Ireland and Engineers Australia, to name but a few, now include the development of a broad range of professional skills (ABET, 2008; Engineers Australia, 2011; Engineers Ireland, 2007). Evidence of a 'strong contribution', a term used by Engineers Ireland, to the development of teamwork, lifelong learning, ethics, communication and self-direction is required in the programme to satisfy the accreditation criteria. Numerous anecdotes of intensive probing for professional skills are relayed by graduates applying for their first job. Many employers devote significant time to assessing the level of professional skills during the recruitment process. Government reports on skills needs often call for greater attention to be paid to the development of critical thinking, creativity and innovation in engineering programmes (e.g., Forfás, 2009). Today’s engineering students are experiencing the effects of curricula changing in response to this new outlook of graduate attributes.

Achievement of high levels of many professional skills is greatly facilitated by a concurrent growth in intellectual development - autonomy in learning, commitment to ethics, willingness to lead and display initiative are hallmarks of the relativistic thinker. The engineer whose intellectual development has not yet passed the dualistic and multiplistic stages and is still reliant on authority for direction and decision making will not score
highly on professional skills, will be unattractive to employers, and has yet to realise his/her potential. Professional skills development can be facilitated by an engineering curriculum that promotes growth in intellectual development. Attention should be paid to the intellectual development of the students throughout the programme to optimise their progression from dualistic to relativistic thinking. Process facilitated student-centred learning can support this growth. When preparing for accreditation events, evidence of a strong contribution to programme outcomes related to design and professional skills can come from measurements of levels of intellectual development among students.

**Intellectual Development Models**

Intellectual or student development models attempt to categorise the stages of development evident in young adult and later years, from adolescence to adulthood. Each stage is associated with a different way of viewing the nature, origin and value of knowledge and the use of evidence in justifying decisions. Progression from one stage to the next reflects an increasing sophistication in one’s view of knowledge and use of evidence to support argument. How one reasons through open-ended problems to provide and defend answers is noticeably different in each of the stages. These stages can be broadly grouped under dualism, multiplicity and relativism. When presented with three alternative models the dualistic thinker will wonder which is the right one (and why the lecturer is presenting the other two); the multiplistic thinker, believing that anything goes, will attempt to add his/her own model to the list; while the relativistic thinker will consider each model based on the evidence used to develop it, judge which is appropriate for a particular circumstance and examine the pros and cons of each (adapted from Rapaport, 1984). A number of intellectual development models exist, the dominant ones being Perry’s model of Ethical and Intellectual Development (Perry, 1999), King & Kitchener’s model of Reflective Judgment (King & Kitchener, 1994), Belenky, Clinchy, Goldberger & Tarule’s Women’s Ways of Knowing (Belenky, Tarule, Goldberger, & Clinchy, 1997) and Baxter Magolda’s model of Epistemological Development (Baxter Magolda, 1992). These models are only briefly described below as the emphasis in this paper is on their relationship to engineering education. Summary reviews of these models can be found in Love & Guthrie (1999) and Felder & Brent (2004).

We know from studies reported by Perry (1999) and King & Kitchener (1994) that the typical outlook of a student entering college is that of the dualistic thinker. This student is young, has just finished school and expects certainty in life. He/she believes there is a right answer to every question and that academics, being figures of authority, know these answers and will provide them. Unquestioning assimilation of knowledge is the goal of this student; questions are only asked to make sure the information has been transcribed correctly. A movement to the next stage, multiplicity, is marked by an acceptance by the student that there is uncertainty in some areas, i.e. a number of right answers may exist but the way an answer is defended is not considered – the student does not yet apply a rigorous approach to choosing a solution. The acceptance of uncertainty is significant, however, as it allows progression to the next stage, relativism, in which uncertainty is now accepted as a permanent feature of life, problems are seen in context and judgements are evaluated based on their adequacy.
During this progression the student’s view of the role of the teacher changes from the only source of knowledge to one source of expertise among others. The student’s view of his/her own role changes from a passive recipient to an active constructor of knowledge – an epistemological change. The view of peers in the learning process changes from irrelevant to legitimate. A student’s position on this scale has a fundamental influence on how the student engages with a learning activity.

Perry’s model (1999) has nine positions, the first six relate to epistemological change and the remainder defined by degree of commitment to decisions. King & Kitchener (1994) focused on epistemological development which influences the way one reasons through ill-structured, open-ended problems. This is labelled reflective judgement and is synonymous with post formal critical thinking. The seven stages in their model are grouped into three categories: (i) pre-reflective thinking, which is similar to dualism and early multiplicity (positions 1 to 3 on Perry’s scale), (ii) quasi-reflective thinking similar to late multiplicity/relativism subordinate(position 4) and (iii) reflective thinking, which is similar to relativism (positions 5 & 6). Students can operate at more than one level. Interviews measure functional level, that evident in independent spontaneous thinking. with support, one can reach a higher optimal level, typically one stage above functional (King & Kitchener, 1994).

**Relationship between gains in intellectual development and professional skills**

A comprehensive set of professional skills can be found in the accreditation guidelines produced by professional bodies in the field of engineering. For example, Engineers Ireland require that a programme facilitate the development of an “understanding of the need for high ethical standards in the practice of engineering…the ability to work effectively as an individual, in teams and in multidisciplinary settings, together with the capacity to undertake lifelong learning [and] the ability to communicate effectively with the engineering community and with society at large” (Engineers Ireland, 2007). These requirements are shared by many accrediting bodies; ABET in the US have similarly phrased outcomes and Engineers Ireland are signatories to the Washington Accord and a member of the European Network for Accreditation of Engineering Education.

Each student’s potential to develop professional skills is greatly influenced by his/her current level of intellectual development. Consider the dualistic thinker: he/she does not view him/herself as a valid source of knowledge, does not yet appreciate that knowledge is a process of construction controlled by the learner and believes there is a right answer to everything which the lecturer will provide. This belief relates to both process and product, i.e. what is to be learned and how. This outlook is not consistent with the attainment of the accrediting body’s programme outcomes outlined above. The ability to work independently on an open-ended problem requires an attitude that one can learn independently of the teacher. To work meaningfully in a group one must view the members as legitimate sources of knowledge. To commit to a set of ethics one must view oneself as owning those values, beliefs and knowledge, not handed down without thinking but the result of considering opinions based on the evidence presented, the way it was
gathered, and the context in which this happened. These are hallmarks of relativistic thinking.

Life long learning, managed independently by the learner, is consistent with a constructivist epistemology where one accepts that knowledge is created through an active process of inquiry with input from various sources and where nothing is final but open to re-evaluation and modification. King & Kitchener (1994) describe the reflective thinker as an active player, not a spectator, in the process of learning who accepts that solutions to ill-structured problems must be constructed. Lifelong learning will be a challenge for the dualistic thinker who is reliant on authority for direction. Likewise, the multiplistic thinker, with an idiosyncratic approach to justifying decisions, will not address knowledge gaps in a rigorous manner.

The view of peers in the learning process changes dramatically across the intellectual development spectrum: dualistic thinkers rely on authority only and do not see peers as valid sources of knowledge; multiplistic thinkers accept peers but do not analyse or evaluate their arguments; while relativistic thinkers accept their peers may have valid arguments worthy of debate. For a group to have a meaningful conversation, i.e. one that leads to the development of understanding, members must view themselves and each other as legitimate sources of knowledge. The ability to work with others in a meaningful way, a key requirement in accreditation criteria, follows the acceptance of the legitimacy of peers which emerges on the path towards relativism.

The first six stages in Perry's model (1999) relate to intellectual development while the last three differ in the way one commits to a judgement in a relativistic world. Perry labelled this 'ethical development' as the change relates to the firmness of beliefs and depth of responsibility associated with one's decisions. Engineers are expected to have 'ethical responsibility' as their actions and decisions address a societal need in most cases. Development of ethical responsibility to a high level requires a corresponding high level of commitment within relativism. Dualistic and multiplistic thinkers are far below this position. They simply accept a set of values handed down (dualism) or believe that everyone is entitled to his/her own opinion without a need to question (multiplicity).

Although not mentioned explicitly by Engineers Ireland and ABET in their accreditation criteria (ABET, 2008; Engineers Ireland, 2007), critical thinking, creativity and innovation are often called for by professional bodies and government skills needs reports (e.g., Forfás, 2009). As explained by King & Kitchener (1994), critical thinking is synonymous with reflective judgement. They distinguish between formal and post formal critical thinking – the former relates to the use of critical thinking techniques while the latter relates to the way one reasons through an ill-structured, highly open-ended problem which depends on one's epistemic assumptions and level of intellectual development. For the dualistic thinker, creativity will be a task to keep the teacher happy by getting the right answer while the multiplistic thinker may be creative but won't critically reflect on the creation. Again, high levels of attainment in critical thinking and creativity accompany high levels of intellectual development.
Specification and design of systems to meet defined needs is a key skill across engineering disciplines specified in accreditation criteria (ABET, 2008; Engineers Ireland, 2007). Grappling to determine solutions for open-ended problems is particularly important in a world that is experiencing unprecedented consumption of its resources. In design, a student develops his/her solution to a problem based on a sound level of understanding of the discipline, often having specified the requirements as well. It must be accepted that many solutions will work; it is not that one is right and others wrong but that each is evaluated based on its properties, suitability for context and tested against the specifications which in turn must be evaluated in a similar way. One must intelligently argue one’s case as well as doing the engineering analysis. This is relativistic thinking; high levels of skill in design are possible for relativistic thinkers. A student that is highly dependent on authority for affirmation of opinions will see design as a guessing game at best or a task to be avoided at worst. For a programme to have a strong contribution to “the ability to design components, systems or processes to meet specific needs” (Engineers Ireland, 2007) it must facilitate the progression of students to relativistic thinking as much as possible.

**Amount of intellectual development during college**

In a number of studies summarised by King & Kitchener (1994), the typical gains in development during four years in college have been measured to be half a stage on their Reflective Judgment model, from a mean of 3.5 (late pre-reflective) in the first year samples to a mean of 4.0 (early quasi-reflective) in the fourth year samples. Significant differences between scores for adult and traditionallage students were not observed. Progression from 3.5 to 4.0 is small but positive. This gain reflects a move from temporary to widespread uncertainty in knowledge, a realisation that some problems are ill-structured and that evidence is required as part of justification. However, widespread uncertainty is also seen in the area of evidence, hence judgement about evidence is also uncertain. A stage 4 thinker assumes others think this way too, including authority figures, which leads to the idea that everyone is equally entitled to an opinion without the need to justify it in a rigorous, considered manner.

A single study in the context of engineering education which measured development of engineering undergraduates over four years scored first year students at 3.3 and fourth-year students at 4.2 on the Perry scale (Wise, Lee, Litzinger, Marra, & Palmer, 2004). This represents a move from early (position 3) to late (position 4) multiplicity but not as far as relativism (position 5). Wise et al. (2004) did not find any relationship between grade point average (GPA) and Perry position in the students they interviewed. This suggests that despite a limitation in intellectual development and associated post-formal critical thinking the engineering student can be very successful in the programme and achieve high grades. In addition, progression along the scale during the college years has been shown to be more modest for engineering students compared to those in humanities and social sciences (Jehng, Johnson, & Anderson, 1993). Lack of progression to relativistic thinking stands in contrast to the high expectations outlined in accreditation criteria.
Role of student-centred learning

Principles associated with student-centred learning, which come from the constructivist view, are well aligned with the promotion towards relativistic thinking. Intellectual development should be seen as a journey from dualism to relativism that is individual for each student, has different start and end points for each and should occur in a steady, progressive way from first to final year. An engineering programme should facilitate as much development as is possible for each student to justify the high levels of skills claimed in the accreditation criteria. It is easy to make claims for the development of ethics, for example, but deliver in a didactic way. In interviews with accreditation panels students can report being forced to think for themselves when the change was only from dualism to multiplicity.

Achieving relativistic thinking after four years in college is indeed a serious challenge given the data reported on final year students. In fact, student-centred learning requires a level of autonomy in learning that lies in relativism for it be as effective as it promises. Dualistic thinkers may not get the point of student-centred learning but must in some way experience the disjunction that exposure to it creates so they are motivated to progress. Their desire is for certainty in everything, both what and how. Modules that satisfy this desire by providing the ‘right’ answer in a didactic approach to learning avoid provoking the students into the difficult intellectual dilemma of moving to the next stage. Although some may appear to be bored in lectures, they are happy to postpone this transition.

King & Kitchener (1994) outline a number of principles to encourage development. One is to match instruction to level. For example, a student at position n on Perry’s scale may not be able to understand an activity aimed at position n + 2 (Rapaport, 1984); this can occur when a student is asked to do a self-directed final year project after years of predominantly didactic teaching. On the other hand, pitching the activity at too low a level will fail to engage. Learning, teaching and assessment strategies should require students to operate at their optimal level (typically functional level + 1).

A student-centred approach to learning, in particular a group-based, project-driven approach such as problem or project-based learning (PBL) in which the learning process is facilitated by the tutor, will allow many of King & Kitchener’s (1994) other suggestions to be implemented. This process includes the use of ill-structured, open-ended problems based on discipline content. The use of small groups allows students to be treated as individuals so each can operate at their own level. Frequent, formative feedback from the tutor on a student’s performance can focus on development issues and require students to move on from their current stage. PBL creates a disjunctive experience in early years, thereby encouraging movement, but can be prevented from becoming excessive by the tutor. Problems can become progressively more complex over time to maintain activity at the optimal level. Assessment can also shift focus: a heavy emphasis on self-directed learning and group collaboration skills can be maintained for the first one to two years; as development occurs this can be relaxed, contact hours can be reduced and feedback can move to other areas such as design, creativity, ethics and formal critical thinking.
techniques. By the final year students should have progressed to as high a level of
development as possible with a corresponding level of attainment in professional skills. In
their work, Wise et al. (2004) found that group-based project-driven modules enhanced
development and argue for the importance of sustaining student-centred learning to
maintain development.

The framework for self-assessment used in Alverno College (Loacker, 2000) is an example
of using reflection on performance to facilitate development. Students are required to
analyse and evaluate performance before suggesting ways to improve based on criteria
provided for them in the early stages but developed by themselves in later years. The
Alverno College Ability-Based Learning Program (Mentkowski, 2000) is very much aligned
with the integrated development of discipline and professional skills throughout the
curriculum. This is in keeping with the development of a reflective practitioner, a label
Schön (1991) gave to those he found to be effective in their professional roles. It also falls
under the ‘engagement’ and ‘participatory’ categories of conception of professional skills
development described by Barrie (2007), these categories being the most complex
identified in his study.

Ways of measuring intellectual development

In research studies, position on the Perry scale is commonly determined by interview,
essay or questionnaire, listed in decreasing order of both time and richness of data
(Moore, 2000). The essay test is known as the Measure of Intellectual Development (MID)
and relates to the intellectual (not the ethical) positions on Perry’s scale. Students are
asked to write three short essays about learning in class, making a decision and choosing a
career. Both the MID and the interview must be assessed by trained raters which is time
consuming and expensive, hence a demand for easier methods is often requested (e.g.,
Wise, et al., 2004). Moore (2000) developed a questionnaire as an alternative which is
called the Learning Environment Preferences test. The Reflective Judgment Interview (RJI)
is used to determine position on the Reflective Judgment Model (King & Kitchener, 1994)
again requiring the use of trained raters.

PBL tutors that have an in-depth understanding of intellectual development can estimate
position through observation in the group meetings. Reading reflective reports where the
students reflect on performance and the learning process also provides an insight to
current thinking. Demands for certainty and direction from authority (e.g. tutor or a web
search engine), the inappropriate use of evidence to justify decisions and lack of in-depth
consideration of alternatives in design and problem solving tasks are easily identified
during group discussions and assessing reflective journals.

Conclusions

The high levels of professional skills demanded by accrediting bodies should be
accompanied by a growth towards relativistic thinking throughout an engineering
programme. Intellectual development and professional skills development are so
intertwined that some terms such as critical thinking and ethical development are used in
describing both. Professional skills such as teamwork, self-directed learning, life-long learning and design are heavily influenced by one’s view of knowledge. Neither a dualistic nor multiplicative outlook is consistent with the degree of independence in thinking that is required for these graduate attributes. Proficiency in these skills is contingent on a mature method of reasoning and a high degree of autonomy.

Engineering programmes do encourage growth but many students only reach multiplicity by the time they graduate despite achieving high grades. This is positive and is a personal challenge for the students resulting in feedback of high demands placed on them by lecturers but is not far enough to satisfy the outcomes specified in accreditation criteria. Student-centred learning, provided through a group-based, project-driven spine in the programme, can facilitate progression to a high level.

It is worth considering the idea of measuring and reporting intellectual development positions of final year engineering students as part of the accreditation process. Such data will allow staff and accreditation panels to determine the levels achieved during all years of the programme so the potential for independence in lifelong learning, design, critical thinking and ethics can be estimated. Programme teams who foster high gains in intellectual development can defend high levels of achievement in programme outcomes prescribed by accrediting bodies that relate to design and professional skills.

References


Engineers Australia (2011). Stage 1 Competency Standard For Professional Engineer. Canberra, Australia: Engineers Australia.


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A systematic consultation process to define graduate outcomes for engineering disciplines

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Abstract: In many countries around the world, there is considerable interest in the development of robust learning outcomes for engineering and other higher education programs. These outcomes underpin the accreditation systems operated by ABET, Engineers Australia, IPENZ, EUR-ACE and the Washington Accord members. In addition, many national governments are developing quality assurance processes that will require university programs to deliver an agreed set of learning outcomes. This paper addresses the development of a systematic, data-driven methodology to develop such learning outcomes.

Introduction

The aim of the Define Your Discipline (DYD) project, funded by the Australian Learning and Teaching Council (ALTC), is to identify and develop an efficient, effective and inclusive consultation process that can be used by discipline stakeholders to define graduate outcomes for programs in their discipline such as engineering, law or pathology. The consultative process has been trialled nationally to develop graduate outcomes for the environmental engineering discipline in the first instance.

This paper describes the DYD stakeholder consultation process that was used in 2010 to capture the views of environmental engineering stakeholders, including academics, practitioners, and recent graduates. The project team worked closely with an Environmental Engineering Project Reference Group which was formed by Engineers Australia's Environmental Engineering College. The College organised the stakeholder consultation workshops, which were held in all mainland capitals. This ensured that data was collected from environmental engineers from both industry and academia.

Context

There is a substantial body of literature that defines the kind of competencies that young graduates should have as they emerge from universities ready for the engineering workplace. These include the US ABET requirements and those from Engineers Australia. In addition, most Australian universities have published a set of generic graduate attributes that would be acquired by all undergraduate students, including engineering students, by the time they graduated from their program. Recent work in Australia also
includes the development of Threshold Learning Outcomes for the combined discipline of Engineering and ICT (ALTC, 2010). A comparison of these competency statements with other international reference statements is included in that publication.

Although these statements are used in national accreditation processes, there is a concern that they are very generic and they fail to capture the technical specifics of each discipline, such as civil engineering or environmental engineering. For example, Engineers Australia’s 2011 Stage 1 Competency Standard for the Professional Engineer (Engineers Australia, 2011) lists the expected graduate competencies for undergraduate engineering programs in three clusters of competency under the headings: 1. Knowledge and Skill Base; 2. Engineering Application Ability; and 3. Professional and Personal Attributes. To satisfy Element of Competency 1.3, a graduate must demonstrate ‘In-depth understanding of specialist bodies of knowledge within the engineering discipline’. The question is: what specific technical knowledge, skills or understandings are essential for a graduate to commence practice in each of the disciplines overseen by the Engineers Australia Colleges?

Some disciplines have made an effort to define the nature of the discipline through more detailed statements. Recent examples include the ASCE Body of Knowledge project (ASCE, 2008) and the American Academy for Environmental Engineers in the US (Arlotta, Baillod et al, 2008). The Australian Environmental Engineering College also defined the nature of their discipline prior to 2004 and this resulted in the publication of the ‘Guidelines on the Design of Environmental Engineering Undergraduate Courses’ which is still in use.

While undergraduate engineering education in Australia enjoys a world-class accreditation system, the processes used by individual Engineering Faculties and Schools to re-orient and update curriculum are often ad-hoc (Carew & Cooper, 2008; Walkington, 2002). Those leading curriculum renewal in an engineering discipline generally rely on input from a local industry advisory group, internet searching to establish what the top international Schools and local competitors are teaching (or professing to teach), and gut instinct on national standards and the likely future direction of the discipline as a whole.

King recognised the need for improved curriculum development processes in engineering by calling for ‘systematic and holistic educational design practices with learning experiences and assessment strategies that focus on delivery of designated graduate outcomes’ in engineering (King, 2008, p. 13). The establishment of clear and agreed national standards in the form of Discipline-specific Graduate Outcomes (DGO) would provide a sure footing for engineering discipline leaders who are reorienting their undergraduate programs to meet current and emerging trends in the discipline.

The DYD Project focuses specifically on Element of Competency 1.3 and through consultations with key discipline stakeholders seek to answer the question ‘What exactly does a graduate from this discipline need to know, understand or be able to do to claim in-depth technical competence in this discipline?’ While Element of Competency 1.3 is the focus of the study, many other competencies have been discussed and contextualised so they better reflect the essential (and desired) Graduate Outcomes of the subject discipline.
The Project Team believes it is more efficient to undertake this work at a national level so that all Engineering Schools can use the same industry authenticated DGOs as a starting point for curriculum renewal. A national approach also overcomes the risk that a School could face if its local stakeholder-defined graduate outcomes were not aligned with the views of the current executive members of the relevant Engineers Australia College, or their representative on an Accreditation Panel. The Project Team addressed these issues by developing the DYD consultative process to invite, value, and integrate the views of the sometimes disparate groups of stakeholders, while keeping a ‘futureproofing’ mindset that focuses on the skills graduates will need in 10 to 20 years rather than current requirements. It is expected that the resulting set of Discipline Graduate Outcomes will be adopted by the relevant College and published and maintained by Engineers Australia. They will then be used by Engineering Schools to inform curriculum development and as a guide by members of future Accreditation Panels. This will ensure that they are reviewed on a regular basis, applied in curriculum renewal, and sustained into the future.

Research Questions

The aims of the DYD project are:

1. To identify and develop an efficient, effective, and inclusive consultation process that can be used by discipline stakeholders to define practitioner-authenticated Discipline Graduate Outcomes.
2. To use the consultative process to deliver nationally agreed Discipline Graduate Outcomes for an engineering discipline.

While conducting the Project, the team is seeking to validate the authenticity of these outcomes by conducting research to test the following hypotheses:

- The DYD Stakeholder Consultation process is an effective, efficient and inclusive process;
- The DYD Stakeholder process enables new and future perspectives to be synthesised with traditional constructs in the development of authentic graduate outcomes.

Theoretical Framework

Numerous tools have been used to develop and authenticate graduate outcomes, particularly for the development of competency-based curriculum in the vocational education sector. For example, occupational analysis tools can be used to observe workers, a curriculum can be developed using the DACUM process (CETE, 2011), and the Delphi technique can be used to iteratively gather and synthesise data from stakeholders until consensus is reached.

The DYD Stakeholder Consultation process is based on the Modified Delphi Technique (Custer, Scarcella, & Stewart, 1999), and uses aspects of the DACUM job analysis method. The design of the process was based on an issue, the definition of a set of graduate outcomes, rather than a method (Gregory, Fischoff, Thorne, & Butte, 2003), and was
informed by the results of a stakeholder analysis (Reed et al., 2009). The analysis determined who had a legitimate stake based on their knowledge and interest.

The self-appointment method was adopted to recruit workshop participants and a selection method was used to form the group of experts who are overseeing the process (Catt & Murphy, 2010). The DYD process was designed to ensure that the input from each stakeholder is equally valued so that the opinions or biases of individuals or groups do not impact on the final outcome. For example, the individual nature of data gathering process ensures that dominant personalities, the professional standing of individuals, or group thinking do not influence the data. The metadata gathered with the data will enable the Project team to assess the influence of each data set, each participant and each stakeholder group on the defined set of graduate outcomes.

**Method, Data, Analysis**

The DYD Stakeholder Consultation workshop begins with a divergent phase. Each workshop participant is asked to write down the tasks that they believe a graduate should be able to do in their first year for two after graduation, including supervised tasks. After an initial period (usually about 30 minutes) the participants at each table collaborate to generate additional tasks. Participants then begin the second stage of the process, the convergent phase, by performing a cluster analysis. This involves laying out all the tasks on a large flat surface and looking for commonalities. The tasks are then grouped and gaps are identified. New task statements are written to cover any gaps. The workshop concludes when the groupings are agreed, and the order of each task in a group is finalised.

The DYD stakeholder consultation process ensures that the contributions from individual participants, as well as stakeholder groups, is captured as the data supplied by each person is identified and each task is numbered. This allows the Project team to track each task through the grouping and synthesis process. The data was analysed for consistency and differences before being synthesised and elaborated using a group of experts to form a set of draft graduate outcomes.

**Findings**

Table 1 shows raw data from several categories from one of the workshops. This shows the kinds of tasks that workshop participants identified for recently graduated environmental engineers. The Table shows the results after the clustering process.

Table 2 shows the clusters from five of the eleven workshops held in 2010. Note the consistent appearance of several of these, such as Design, Modelling, Auditing, and Management.

What has been interesting about the results of this process is that the cluster analysis yielded quite unexpected results. Our hypothesis was that clusters would form around application areas in environmental engineering: soil problems, water, energy, noise, air pollution and so on. Thus, we expected that these statements would, together, form a more
detailed layer in the graduate outcomes hierarchy, one step below, and expanding on, Engineers Australia’s Stage 1 Competency Standards.

<table>
<thead>
<tr>
<th>Process</th>
<th>Examples of identified tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigation</td>
<td>1. Executes simple sampling plans for collection of air, water and soil samples.</td>
</tr>
<tr>
<td></td>
<td>2. Collect, evaluate and interpret water quality data and prepare a report on the results and recommended solutions to improve the water quality.</td>
</tr>
<tr>
<td>Audit and compliance</td>
<td>1. Audit the environmental compliance of a small, low complexity project against its environmental approval or management plan.</td>
</tr>
<tr>
<td></td>
<td>2. Undertake audits of specific sites or parts of an organisation to identify adequacy of current practice against significant environmental aspects of the operation.</td>
</tr>
<tr>
<td>Design</td>
<td>1. Contribute to contaminated site remediation design/strategy.</td>
</tr>
<tr>
<td></td>
<td>2. Design a catchment management plan for both groundwater and surface water catchments.</td>
</tr>
<tr>
<td>Modelling</td>
<td>1. Develop inventories of emissions including the physical, chemical and spatial characteristics of the sources. Manipulate and combine data to arrive at assessment of aggregate effects.</td>
</tr>
<tr>
<td></td>
<td>2. Calculate mass balances and identify flux paths e.g. water or nutrient.</td>
</tr>
</tbody>
</table>

Instead, clusters consistently formed around six major work types: *investigation, impact assessment, design, modelling, audit and compliance, and environmental management*. Of these, half of them are quite generic skills – investigation, design and modelling. The remaining three have a distinctly environmental feel – impact assessment, audit and compliance, and environmental management.

So, how do these compare to the common accreditation requirements as discussed earlier? Table 3 shows such a comparison.
What is interesting about this is that the categories created at the workshops are almost solely from category 2 of the EA accreditation guidelines, namely "Engineering Application Ability". Categories 1 (Knowledge and Skill Base) and 3 (Professional and Personal Attributes) are listed in Table 3 for completeness.

Considered also with the application domains in environmental engineering (land/soil, water, air, noise, energy, etc), the whole picture becomes rather complex, with at least three axes of knowledge and skills required:

- Application types – investigation, design, modelling, impact assessment, management, audit and compliance
- Application areas – soil, air, water, noise, energy, etc
- Professional and personal skills – communication, teamwork, ethics, information, self management and evaluation, etc

Each of these is underpinned by a sound body of knowledge and skills (EA’s category PE1).

We propose a three dimensional model (Table 3 and Figure 1) to represent the scope of the environmental engineering discipline. Other disciplines share some aspects of this model.
Table 3 – Comparison of 6 work types with Engineers Australia's accreditation guidelines

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Category</th>
<th>Engineers Australia Element of Competency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Investigation</td>
<td>2.1. Application of established engineering methods to complex engineering problem solving.</td>
</tr>
<tr>
<td></td>
<td>Modelling</td>
<td>2.2. Fluent application of engineering techniques, tools and resources.</td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>2.3. Application of systematic engineering synthesis and design processes.</td>
</tr>
<tr>
<td></td>
<td>Impact assessment</td>
<td>13. In-depth understanding of specialist bodies of knowledge within the engineering discipline. (Indicator: Proficiently applies advanced technical knowledge and skills in at least one specialist practice domain of the engineering discipline).</td>
</tr>
<tr>
<td></td>
<td>Environmental management</td>
<td>2.4. Application of systematic approaches to the conduct and management of engineering projects.</td>
</tr>
<tr>
<td></td>
<td>Audit and Compliance</td>
<td>1.6. Understanding of the scope, principles, norms, accountabilities and boundaries of contemporary engineering practice in the specific discipline.</td>
</tr>
<tr>
<td>2</td>
<td>Generic skills</td>
<td>1.2. Conceptual understanding of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. PROFESSIONAL AND PERSONAL ATTRIBUTES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.1. Ethical conduct and professional accountability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2. Effective oral and written communication in professional and lay domains.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.3. Creative, innovative and pro-active demeanour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.4. Professional use and management of information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.5. Orderly management of self and professional conduct.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.6. Effective team membership and team leadership</td>
</tr>
<tr>
<td>3</td>
<td>Engineering applications</td>
<td>1.1. Comprehensive, theory-based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.3. In-depth understanding of specialist bodies of knowledge within the engineering discipline.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.4. Discrimination of knowledge development and research directions within the engineering discipline.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.5. Knowledge of contextual factors impacting the engineering discipline.</td>
</tr>
</tbody>
</table>
Where to from here?

The work in 2011 is confirming the results through additional workshops, elaborating the work types in more detail in specific application areas, such as contaminated land.

The intention is also to develop a range of task-oriented learning materials and project ideas that will help academics to teach the six core skills. These learning resources will be made available via the web. Contact the authors if this is of interest to you.

Conclusions

The workshops from this process have demonstrated surprisingly consistent outcomes for the scope of environmental engineering, with six aspects of environmental engineering work identified. The same process is being tested in other disciplines. The results confirm the accreditation framework used by Engineers Australia (which is well aligned with other accreditation bodies around the world through the International Engineering Alliance).

The authors have also proposed a three dimensional model for understanding the complexity of these learning outcomes, embracing application types (kinds of work), application areas (domains of application), and general purpose professional and personal skills that underpin engineering work. This should be similarly useful in other domains of engineering.

We believe that current accreditation processes tend to oversimplify the complexity of engineering practice, which is better represented by the three dimensional model shown. Engineering curricula must help students to learn skills and knowledge on each of these three dimensions within a limited period of 4-5 years and a limited number of subjects.

The challenge for good curriculum design is to provide adequate coverage of all of the key skills, which requires that many subjects will have three separate purposes: developing skills in one of the six application types, familiarising students with one of the application areas, while also continuing to develop their professional and personal skills. That makes curriculum design challenging and it makes teaching challenging, but also more rewarding, because each subject needs to blend together these three learning factors, combining theory with practice, underpinned by professional skills.
References


Engineers Australia (2011). Stage 1 Competency Standard for the Professional Engineer.


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The Development of Assessment Tools Using Phenomenography

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Abstract: A major challenge in Engineering Education is assessing students’ understanding of complex concepts and/or the strategies that are proposed to develop them. Often appropriate assessment tools do not already exist for the concept of interest, motivating researchers and educators to develop and validate their own instruments. This process can be further complicated if the underlying frameworks have not yet been established. This paper describes a new model of assessment development which uses phenomenography as a starting point for the development of the assessment tool. In phenomenographic studies, the focus of the research is the variation in how a phenomenon is experienced which yields empirical information that identifies both different dimensions of and different levels of sophistication in the target populations’ understanding of the phenomenon. These findings can be used to construct an underlying framework of the concept of interest, providing a research-informed approach to assessment tool development.

Introduction

One of the major challenges in Engineering Education is assessing understanding of complex concepts. Having reliable and valid assessment tools is important because assessment of the students’ understanding helps students to learn, as students receive feedback on their current level of proficiency or understanding, and helps instructors to teach, as they are able to use this information to shape the instruction so that it better matches students’ current state (Bransford et al., 2000). Furthermore, assessment tools provide a mechanism for evaluating the effectiveness of different teaching strategies.

In Engineering Education, there are many concepts where appropriate assessment tools do not already exist, motivating researchers and educators to develop and validate their own assessment instruments. However, this process can be further complicated if the underlying theoretical frameworks have not yet been established. For example, what does it mean for a student to have a more comprehensive understanding of human-centered design? Although the design literature describes variations in design thinking and
behavior, it is not easily operationalized into an assessment tool. This paper describes a new model of assessment development which uses phenomenography to develop the underlying framework. In phenomenography, the focus of the research is the variation of how a phenomenon is experienced which yields empirical information identifying both different dimensions of and different levels of sophistication in the target populations’ understanding of the phenomenon. Thus, the results of a phenomenographic study can be used to construct the underlying framework of the concept of interest which provides a research-informed approach to development of an assessment tool.

Context/Background

Design is a central and distinguishing activity of engineering (Atman et al., 1999; Bucciarelli, 1994; Simon, 1996), and as such, there has been a growing emphasis on including design in the engineering curriculum (Dixon & Duffey, 1990; Dym et al., 2005). To do this, engineering programs must have an understanding of design and how students learn design (Newstetter & McCracken, 2001). Many studies have looked at design including characterizing differences in first-year and senior engineering design abilities and behaviors, (Atman et al., 2007; Bailey & Szabo, 2006), information gathering behavior (Bursic & Atman, 1997), and conceptions of design (Newstetter & McCracken, 2001). Existing design assessment instruments include simulation tasks (Sims-Knight, Upchurch, & Fortier, 2005), verbal protocol (Atman et al., 2007) and critique of design processes (Bailey & Szabo, 2006).

Within design, there has been a shift to human-centered design processes as leading design firms such as IDEO attribute their success in innovation to human-centered processes (Brown, 2008; IDEO, 2010). In addition, engineering education has increasingly incorporated human-centered design processes and focused on the development of skills needed for design thinking (Agogino, 2008; Buchanan, 2001). However, although there are instruments that assess general design process knowledge, there are not currently instruments to assess human-centered design. And although human-centered design is described in the literature, there is not an underlying framework supported by research data in which to assess a students’ understanding of human-centered design.

Research Questions

Traditionally, assessment instruments are developed according to an underlying theoretical model (Messick 1995). Frameworks used in engineering education include Knowledge, Attitudes and Behavior (Yun, Cardella, Purzer, Hsu, & Chae, 2010), model, interpretation and observation (Beyerlein, et al., 2005), and Tinto’s theory of student departure (Tinto, 1987). However, there was not an underlying model of what it meant to take a “human-centered” approach to design. Therefore, the following research question guided the study: What are the qualitatively different ways in which students experience and understand human-centered design in the context of “designing for others”?

The importance of the study was to provide a basis to assess learning of human-centered design by developing the underlying framework of students’ experiences of human-centered design. The ability to assess students’ understanding of human-centered design

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allows educational programs to determine what impact their programs are having, and what aspects of the educational program are most effective. Furthermore, this work provides a model that can be adapted to a wide range of contexts of a research-informed approach to assessment tool development, which is the focus of this paper.

Theoretical Frameworks

While no theoretical framework exists for human-centered design, related frameworks were used to inform the research. Building on previous studies of design processes and expert-novice differences, the goal of this study was to characterize the qualitatively different ways in which the students experienced human-centered design. The methodology selected for this study was phenomenography, a qualitative approach to research in which the “unit of phenomenographic research is a way of experiencing something, ..., and the object of the research is the variation in ways of experiencing phenomena” (Marton & Booth, 1997). Phenomenographic approach emerged from recognition that the qualitatively different ways in which learners experienced or understood a phenomenon were related to the qualitative differences in the outcome of that learning (Marton, 1981; 1988). It is important to note that phenomenography is different from phenomenology. Although both qualitative methods are concerned with how a phenomenon is experienced, phenomenology investigates the essence of a phenomenon whereas phenomenography seeks to understand the variation (Patton, 1990).

Phenomenography has been used to study a wide variety of phenomenon from students’ experience of learning object-oriented programming (Stamouli & Huggard, 2007) to the quality of care in the psychiatric setting (Schroder, A., Ahlstrom, G., & Larsson, 2006). Related to design, phenomenography has been used to explore sustainable design (Mann, Radcliffe, & Dall’Alba, 2007), design students’ experience of engagement and creativity (Reid & Solomonides, 2007), and the ways that design has been experienced by professionals in a variety of disciplines (Daly, 2008).

The outcomes of phenomenographic study are the categories of description and outcome space. Marton and Booth (1997) state that within that outcome space, “The qualitatively different ways of experiencing a particular phenomenon, as a rule, form a hierarchy” (p. 125). This is based on the expectation that since the categories of description represent the relationship between the phenomenon and the person experiencing the phenomenon, the categories themselves should be logically connected through the experienced phenomenon (Åkerlind, 2005). Furthermore, since phenomenography looks at the variation within the sample group as a group, the outcome space provides a way to look at the collective experience of the phenomenon versus the individual experience. As such, the categories of description and outcome space provide a framework for rubrics and other assessment tools.

Methodology

The phenomenographic study explored the variation of students’ experiences of human-centered design in the context of “designing for others”. Students were recruited from a
variety of design experiences including service-learning courses, EPICS (Coyle, et al, 2005), and Engineers Without Borders (EWB) or Engineers for World Health (EWH). It also included more traditional design courses, internships, and other experiences such as senior design courses, and the first-year "Usercentered Design" courses. Using maximum variation sampling (Creswell, 2003; Patton, 1990), 33 participants were selected to maximize variability of experiences based on type, duration and client of the design experience and the student's major, academic year, sex and ethnicity. Many of the students participated in multiple experiences in which they "designed for others." IRB approval was obtained prior to the commencement of the interviews.

The data collected for this study was interview data from semi-structured interviews that prompted students to reflect on their experiences with stakeholders and how they go about designing and creating a product that will meet the needs of people. Each interview began with an identical opening scenario, and included follow-up questions to elicit more discussion about the phenomenon. The interviews were transcribed verbatim and coded with a pseudonym. The phenomenographic analysis process was strongly iterative and comparative and began by reading and re-reading the entire set of interviews (Akerlind, 2005; Bowden and Green, 2005; Marton & Booth, 1997). Considering each transcript holistically and within the context of all of the interviews, the transcripts were sorted into initial categories. Similarities and differences among the groups were described, which served to help clarify and refine the categories. Categories were formed based on the content of the transcripts themselves, rather than base on theoretical framing from the literature. Several iterations of this process were completed. When the categories began to converge, analysis of the structural relationship between the categories began and continued until an outcome space which contained as few, distinct and logically related categories as possible (Marton & Booth, 1997). For more detailed information regarding the study, please see (Zoltowski, Oakes, & Cardella, 2012).

Findings

Analysis of the data yielded seven qualitatively different ways in which the students experienced human-centered design within the context of “designing for others” which are shown in Figure 1. These different ways of understanding are referred to as categories of description. Each category reflects a qualitatively different way of understanding or experiencing human-centered design. Inclusion in the specific category was based on the student designers' understanding of human-centered design as a whole as reflected in the experiences they shared in their interviews. The students themselves are not assigned to that category, but their experiences as described as part of the interview. The categories of description resulting from the study formed an outcome space with two distinct, but not independent, axes: "Understanding of the Users" and "Design Process and Integration" (Figure 1). The axes depict complex constructs and have scales that were derived from the categories themselves and are ordinal in nature. Five of the seven categories, namely categories 3 through 7, were related such that, starting with category 3, each subsequent category represented a more comprehensive way of experiencing human-centered design. Although logically related, the experiences of two of the categories, categories 1 and 2, were not included in that group. The critical differences between the categories provided
the basis for developing the hierarchy as represented in the outcome space. Therefore, categories that are more comprehensive will have aspects that are only found in that category as well as aspects that are found in the categories that are less comprehensive.

![Outcome Space for Students' Ways of Experiencing Human-Centered Design](image)

**Figure 1: Outcome Space for Students' Ways of Experiencing Human-Centered Design**

The overall structure of the outcome space, consisting of the nested hierarchy of categories 3 – 7 and two distinct categories, suggest a number of things. First, that there is both a "design" aspect and an "understanding of the users" aspect reflected in the experiences of human-centered design and both are needed in the development of more comprehensive ways of experiencing human-centered design. Therefore an appropriate assessment instrument would measure both of these dimensions. Second, the categories of description of categories 3 – 7 and the graph of those categories not only define what it means to have a more comprehensive way of experiencing human-centered design, but describe the progression of development of the more comprehensive understanding of the concept. Thus an appropriate assessment would measure the abilities that distinguish each category from the other four. As such, this framework could be used to develop a
rubric (Table 1) which can be used to evaluate responses from a design task and/or reflection questions.

Table 1: Example Rubric for Assessing Human-Centered Design

<table>
<thead>
<tr>
<th>Category of Description</th>
<th>Understanding of User</th>
<th>Design Process and Integration</th>
<th>Users Involved in Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1: Technology-Centered</td>
<td>Not focused on understanding</td>
<td>Technology-centered</td>
<td>Users not included in design in meaningful way</td>
</tr>
<tr>
<td>Category 2: Service</td>
<td>Want to help or positively benefit</td>
<td>Little or no design process</td>
<td>Communicate with users to keep in loop</td>
</tr>
<tr>
<td>Category 3: User as Information Source Input to Linear Process</td>
<td>Gathers information from users at beginning of process</td>
<td>Linear design process</td>
<td>Stakeholders included minimally throughout</td>
</tr>
<tr>
<td>Category 4: Keeping the Users’ Needs in Mind</td>
<td>Gathers information about needs from higher level stakeholders or experts</td>
<td>Focus on needs; some iteration</td>
<td>Involves primarily higher stakeholders</td>
</tr>
<tr>
<td>Category 5: Understanding the Design in Context</td>
<td>Understanding context, use and needs</td>
<td>Somewhat integrated to minimal integrations</td>
<td>Involves higher stakeholders in some design decisions</td>
</tr>
<tr>
<td>Category 6: Commitment to Involving Stakeholders to Understand Perspectives</td>
<td>Considers context, use and needs, focus on users</td>
<td>Integrated to highly integrated, depending on design experience</td>
<td>Stakeholders, particularly end-users and involved in process</td>
</tr>
<tr>
<td>Category 7: Empathic Design</td>
<td>Develops relationship with users, understanding context, use and needs</td>
<td>Highly integrated</td>
<td>Stakeholders, particularly end-users are very involved in process</td>
</tr>
</tbody>
</table>

Recommendations/Future Research Plans

The use of phenomenographic study can be an effective strategy to develop underlying frameworks for a concept within engineering education if it does not currently exist. As illustrated in the example, the results of the phenomenographic study—the categories of description and the outcome space—describe the qualitatively different ways that the target population experienced and understood the phenomenon or concept of interest. They also described a hierarchical relationship among the categories which described a progression of that understanding. As such, these and other findings from phenomenographic studies can provide a basis for the development of rubrics and other assessment tools that identify key differences in understanding a concept and also describe and categorize more comprehensive understanding of that concept.

We are in the final stages of the development of a design task and associated rubric to assess students’ understanding of human-centered design based on the framework developed through the example phenomenographic study described in this paper. Our future plans include validation of the instrument, and once that is complete, the evaluation of educational programs and experiences to determine which are more effective in developing students’ understanding of human-centered design.
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Abstract: The present study proposes an original educational methodology that fits perfectly into the new educational strategies arising from the European Space for Higher Education. Students were required to design a real experiment and carry it out in order to present a report of the obtained results and finally realize an oral presentation in the class. The findings showed that, comparing with previous courses, innovative teaching procedures performed resulted in higher grades and an increase of the motivation among students for the subject and, broadly, for the degree. Moreover, this activity not only stimulates student’s creativity and autonomous learning but also enhances crucial transversal skills such as teamwork, communication skills and the promotion of a deep comprehension of scientific methodology in an appealing and more attractive way.

Introduction

The best answer to the question, "What is the most effective method of teaching?" is that it depends on the goal, the student, the content, and the teacher. But the next best answer is, "students teaching other students." (McKeachie, 1991).

Changes in the teaching of sciences have been widely reported in recent years, especially at the upper secondary and introductory university levels as the European Space for Higher Education has prompted new educational strategies, involving changes to courses, curricula and instructional methods.

In this way, new curricula has placed greater emphasis on the importance of practice and the learning process of students, replacing the standard lecture with active learning strategies into the daily routine of classroom instruction.

According to McKeachie (1991), active learning refers to "experiences in which students are thinking about the subject matter" as they interact with the instructor and each other (Gamson, 1991). This learning format has proven very effective in science teaching. Research shows that passive involvement generally leads to a limited retention of knowledge of students (Jaques, 1992) meanwhile after an active learning, such as simulating a real experience; students tend to remember the 90% of what they have learned (Dale, 1969). As a result, active and cooperative learning has become an important approach used by many teachers.
In this context, laboratory activities mean a great way to promote students’ participation, engaging and motivating them in interacting with each other while learning the scientific inquiry they need. Certainly, experiments allow students to observe phenomena, test hypotheses, and apply their understanding of the real world (Gorghiu et al., 2007).

However, it has been observed that in a laboratory activity students have to carry out an experiment only by following some repetitive and highly predictable steps. On the other hand, in the case of the active learning, it is necessary the participation of the students as well as the development of their skills in order to propose, invent, carry out and explain in a different way an experiment designed by them. Thus this methodology resembles practice in the real world of science.

Thus, whereas testing experiments are usually conducted to test or disprove a certain hypothesis, idea, or a prediction (Etkina et al., 2002), the present study describes and approach to classroom experiments in which they serve roles closer to that in the practice of engineering and physics (Born, 1943). According to this, students were encouraged to make observations and elaborate a simplified theory that explains them, as this pedagogical technique has proved to be more effective than the previous one (Laws, 1997).

Finally, the aim of this article is to describe a project-based lesson plan on Materials Science which was applied for first time in the Materials Engineering Degree. This activity was a part of a Teaching Innovation Project and the obtained results proved to be a very beneficial and satisfactory lesson-plan for the students as well for the professors.

**Method**

This activity was conducted during the second term of academic year 2010-2011 in the first course of the Materials Engineering Degree as part of a Teaching Innovation Project carried out at the Technical University of Madrid. Several actions were leaded to facilitate student learning and to improve teaching quality at the subject Structure of Materials II. These actions involved devising and implementing two laboratory experiments and proposing students to design a real experiment and carry it out in order to present a report of the obtained results. This second activity was a significant part of the evaluation of the students, up to a 30%, for this reason it is necessary the supervision of each work by an instructor.

Additionally, interviews to obtain feedback from the students and video recordings of several experiment executions were done in order to gather data.

According to the guide given to the pupils, the aim of their Projects was to design and carry out a scientific experiment paying close attention to the next aspects:

- Establishing a basic hypothesis by defining a conceptual system based on a science subject where the only restriction is that the study should focus on the structure and properties of non-crystalline materials, as this is the main topic of the second semester subject Structure of Materials II.
• Physical description of the system. They should be able to observe simple or complex systems and to name and describe them macroscopically and microscopically.

• Qualitative observation of the system. Being able to observe changes in these systems due to changing conditions (temperature, pressure, humidity, composition, time...) and describe its evolution.

• Quantitative analysis of the system. Quantifying the change of system properties by measuring macroscopic parameters under the circumstances described in the previous section.

• Creation of a model of behaviour. Setting an equation to predict the behaviour of the system under different conditions.

• Correlation of the model. Finally, the most important aspect is to verify the initial hypothesis, and to check whether it is met or not and why. The correctness of the hypothesis is not relevant as long as the students are able to give a good interpretation of the phenomena.

To promote crucial transversal skills such as cooperative learning and interactive engagement between classmates (Bejarano et al., 1997), students were divided up into smaller groups of two or three people. The reason for giving a flexible range of groupings was because they had regular classmates to work with in a group, thus problems resulting from unfamiliarity with partners during cooperative learning were reduced to a minimum. Each group was led by a particular supervisor (doctoral researchers and undergraduate teaching assistants) who helped them by solving doubts that may occur during the progress of their projects and also to prevent potentially dangerous or inappropriate experiments.

Before setting up the project, students were encouraged to search for information from the internet and to consult the bibliography provided by the teacher as there are a large amount of websites from publishers, educational institutions and other sources that include very valuable interactive formats that support a variety of learning styles and topics.

After their research, pupils submitted an initial report defining the proposed experiment, and performed an oral presentation to their classmates, not only to avoid similar projects but also to acquire effective communication skills.

Then, they conducted their experiments, collected data, and interpreted results by themselves. In all these activities students were recommended to follow the main aspects of the scientific practice: asking questions, setting hypotheses, design experiments, identify and control variables, collect and interpret their data.

In the final stage of the activity students submitted a final report and presented their findings to class. After their speech, their classmates were encouraged to ask questions about items and issues from the projects on display, being the consistency and originality of these questions another parameter which could mark the activity.
Main results

In order to evaluate the work of each group and also the efficiency of the activity it was necessary to evaluate every step of their progress. Quantitative data from the first assessment are shown in the Figure 1. In this step, once each group has presented a pre-project, the students of the other groups evaluated the presentation and the work of their classmates. There were 26 groups and each student (75 students) had to evaluate 8 of them that were randomly chosen.

The evaluation criteria were the level of the compliance of the points shown below:

- Clarity of the objectives and the hypothesis
- Proposed methodology
- Clarity of the explanations and relation of the experiment with the subject
- Originality of the experiment
- Feasibility of the experiment

As it can be observed from the representation of the fraction of students versus the evaluation mark (Figure 1), students evaluated rather generously their classmates to encourage them. The lowest evaluation mark given was 2.7 and the highest was 5, achieved by only a few groups. The mean of the pre-evaluation was 3.21 (fair). This pre-evaluation helped and stimulated students in order to carry out the science project. Moreover, it worked as a push to start with the design of the experiment and the information search.

Figure 2 shows the quantitative data of the post evaluation. In this case, each group had to present a report of the science project to make a public presentation in classroom and finally, to answer the questions by their peers and the teacher. However, the main difference between the pre-evaluation and the post-evaluation is that in the second one, the professor evaluates the work of the groups and each one of the students.

So, it can be observed that there is more scatter in the results than in the case of the pre-evaluation, and moreover, although the mean of the post-evaluation is 3.1 (good), very close to the other one (pre-evaluation), it is obvious that there is a significant improvement of the evaluation marks. The scatter is due to the final presentation of the science projects, where some groups showed a poorer performance while others had an excellent level.

Additionally, when students were asked about the scientific skills acquired through this education plan it was found that almost all of the students were more familiarized with science and understood the process of the scientific projects. Moreover, some opinions of the students are as follows:

"This education plan has provided high motivation about materials science and scientific experiments"

"The students overcome the fear of speaking in public"
“Now I understand and I can explain phenomena about the structure of materials and their function”

Figure 1: Pre-evaluation. Presentation of the fraction of the students versus the evaluation mark \((1-5)^*\).

\*5= very good, 4= good, 3= fair, 2= poor, 1= very poor

Figure 2: Post-evaluation. Presentation of the fraction of the students versus the evaluation mark \((0-5)^*\).
Another remarkable point is the participation of the students at the moment of the presentation of their works (Figure 3). Almost all the students were interested in understanding the work of their classmates, asking them in order to remove any doubt.

![Figure 3: Participation of the students, asking about the work of their classmates.](image)

Results from the first evaluation of the experiments showed that, at first, students did not know how to apply the necessary tools to carry out the experiments. However, all the groups presented many ideas, although some of them were not able to design their experiment. Their teacher had to guide and help them all the time. After finishing the experiment and its report, most of the students successfully completed their task, although there were a few students that did not participate in the same way.

To sum up, when finally the students conducted their science projects, they had the opportunity to search for information they were interested in and design experiments by using affordable and simple materials. Generally, there was a very good collaboration between students and all the groups tried to design and carry out an original and different experiment. Some of the groups formulated and tested hypothesis, identified and controlled variables by themselves, but at times they asked for help about the best way to collect and analyse data.

**Conclusions**

The purpose of this paper was to analyse the results from the implementation of active learning initiatives in the subject of Structure of Materials II. These procedures consisted of the development of innovative experiments by the students. Several actions were developed in order to evaluate students’ work. These actions involved not only valuing students’ science projects but also laboratory reports, oral presentation and classroom observation and attention.

The innovative teaching procedures which have implemented have achieved better overall results, not only in terms of number of passes, but also in higher grades and attention of students. Continuous assessment has also facilitated them to follow a course that they
considered difficult at first, thereby decreasing the percentage of students who abandoned the subject. The feedback provided by the students has been very positive.

Significantly, introducing science projects in the subject had achieved not only proposed objectives but also some additional benefits have been found:

- Acquisition of specialized knowledge and vocabulary and developing students’ communication skills.
- Enhancing public speaking skills. Students were able to produce highly organized and articulate speech.
- Increasing students’ attention towards the subject, as seen in certain groups who even developed projects well above expectations.
- Helping students to develop mathematical and qualitative models based on experimentation.
- Development of seeking and information literacy skills, since, as many authors established (Barranoik, 2001; Scott & O’Sullivan, 2005), students still demonstrate several lacks when selecting searching terms or evaluating the credibility or accuracy of web sites.
- Increasing student-teacher and student-student interaction which in turn improved cooperative learning.
- Stimulating teachers’ motivation. As it has been found that students’ degree of interest is higher, they participate more in class and understand better what they are told. Being this an advantage, innovative methods have also increased the workload of the teaching staff so cooperation among teachers is now more necessary.

Finally, we can conclude that this activity was successful in motivating students about the acquisition of general and transversal skills. According to Fatimah Ali et al. (2006), organization and planning, oral and written communication, cooperative work, critical thinking or creativity will often mark important professional opportunities in an engineer’s career so University needs to endow students with technical as well as communication skills.

References


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An architecture for virtual and remote laboratories to support distance learning

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Abstract: This work describes the experience of the authors regarding the design, development, analysis, and exploitation of Web-based technologies for creating an online experimentation framework with distance education purposes. This framework is specially design for scientific and technical courses that require a quite important presence of experimentation. Every component belonging to the proposed structure for these kind of portals is integrated into a free modern Learning Management System (LMS) that enhances collaborative work. The features, use, and integration of this LMS (Moodle) along with the other required tools are detailed. The proposed framework was used to implement a network of remote and virtual laboratories for control engineering education (AutomatLabs) that is presented here too as an example of its application.

Introduction

Many universities, such as the Spanish University for Distance Education (UNED), offer to thousands of students all over the world the possibility of following graduate and post graduate studies at distance (e.g. Harry, 1999). In order to provide a high quality education with these conditions, these institutions need to use modern distance education resources, methods, and technologies.

The research on the development, improvement, and exploitation of these issues has produced important results in the last years such as the Web-based laboratories. These online labs are already quite well established in several scientific and technical disciplines because they help to illustrate scientific phenomena that require costly or difficult-to-assemble equipment (e.g. Chang et al., 2005). Other tools appeared due to the need of distance education resources are the LMSs, used for the administration, documentation, tracking, and reporting of training programs, classroom and online events (e.g. Ellis, 2009). In open universities, the introduction of these kind of teaching methodologies is a key piece to cover needs from students who must conjugate work and study and it is commonly accepted that digital media (such as simulations, videos, interactive screen experiments or web laboratories) can positively impact students knowledge, skills and attitudes (e.g. Kozma, 1994).
Web-based laboratories can consist of two different parts: the simulated experiment and its real (remotely controlled) counterpart. In particular, Gratch et al. (2007), state that simulations have evolved into interactive graphical user interfaces (GUIs) for student exploration (e.g.). Virtual Laboratories (VLs) are a particular approach to hands-on laboratories by means of these computer based simulations which focus on presenting both similar views and similar ways of work to their traditional counterparts. Thanks to these tools, students are able not only to observe the behaviour and evolution of the simulated systems but also to manipulate their parameters. In engineering, remote real experimentation has been widely available for more than a decade (e.g. Salzmann and Gillet, 2007) and the importance and benefits of remote laboratories (RLs) in this discipline education has been widely studied. Unlike VLs, in which the actions applied to the virtual system and its reactions are simulated, RLs use real plants teleoperated.

All these experiences have been possible thanks to the advent of the Web, which has promoted a wider adoption of remote experimentation since Web browsers are the ideal tool to ubiquitously execute the client application. However, developers face extra work when transforming an existing local system into a Web-based environment as, even though they are used to manage hardware and software in a local control system, new problems arise when making it accessible via the Internet. This work offers a complete and well tested solution to this problem: a general framework for developing VLs and RLs that are deployed via the Internet by means of a free LMS.

Most works on virtual and remote laboratories are mainly focused on solving the technical issues related to the building of web-based lab solutions and not providing specific software tools designed to meet these goals and some basic guidelines on how to use them. In general, they do not take into account the programming issues that hinder control engineering teaching staff when designing and developing VLs and RLs (e.g. Casini et al., 2009). Park et al. (2005) found that the developments proposed in the literature to create remote experimentation systems are usually custom made solutions and hence, their conception, selection of software tools, and global architecture are not simple tasks due to the high offer in the existing software tools. This paper provides a conceptual framework that is general and simple enough to be applicable to any technical or scientific course that needs to provide experimentation as a complement to the theory lessons. Moreover, when provided, the web environments of the previous works and many others (e.g. Gurkan et al., 2008) do not consider the social context of interaction and collaboration among students (and between teachers and students) in traditional hands-on laboratories. The framework presented in this work is based on three software tools: Moodle to create collaborative Web learning environments, Easy Java Simulations (EJS) to easily create the Java applets that serve as GUIs in both VLs and RLs, and LabView for the computer programs to control the remote hardware in the RLs.

The paper is organized as follows: Section 2 gives a global vision of the framework proposed in this paper to Web experimentation portals, its structure, and the use and features of the tools it requires. Section 3 presents an instantiation example of this framework applied to a control engineering course (AutomatLabs). Finally, in Section 4 some conclusions and future work lines are given.
E-learning platform framework

This section presents a general framework based on a systematic approach using two types of resources. It can be used to develop Web experimentation portals with educational purposes, especially for technical and scientific courses. Figure 1 shows the structure of an e-learning platform to publish remote and virtual laboratories on the Internet.

![E-Learning platform architecture](image)

Figure 1: E-Learning platform architecture

The Web environment, based on Moodle, provides students with all the theoretical documentation, protocol tasks, and complementary information they may need as well as communication channels between students and professors (e-learning resources). The Java applets of the virtual and remote laboratories used for the experimentation part of the course (experimentation resources) are also contained in this system and integrated into the LMS. Moreover, during the virtual or remote experimental sessions, they can save the obtained data in the server. These files are placed in a file repository within their personal account of Moodle and so, students can access them from any computer with an Internet connection and use them to write the laboratory reports which are finally sent to the instructors by means of a submission application of this LMS.

Experimentation Resources (Virtual and Remote Labs) Implementation

This stage of implementation is divided into two steps and involves the methodology to design and build: 1) the GUI, which serves for both the VL and the RL, and 2) the server application which acts as a gateway with the real plant in the laboratory (only used by the RL). Both tasks must be done for each of the VL and RL that would be provided in the online experimentation portal.

1. Client GUI: The GUI applications are distributed as Java applets (developed with EJS) to Web browsers. By means of the applet GUI, students can observe the effect in the dynamic behavior of the processes during their virtual or remote manipulation. They can also save data registers (parameters and measurements) or images (graphs with plotted data) of the experiments for later analysis. These files are saved in the server, sent from the applet via FTP using the Linlyn class and get stored in the personal folder corresponding to the students Moodle account. Communication between these client applications and the server ones is described in the next section.
2. Server Application: The development process of the second step is addressed by means of the well-known client and server architecture. Figure 2 shows the basic structure of these applications, where a remote client manipulates a process located in the laboratory through a server computer working as a middleware communication layer. Visual feedback of the distant equipment is usually provided by a webcam that points to the real equipment.

TCP/UDP links are commonly used for exchanging data and commands between both sides based on a design pattern known as command-based architecture. The server side executes three tasks concurrently: the Command Parser, the Sender, and the Acquisition and Control-Loop. The command parser receives commands from the client, interprets them, and executes the requested actions. When no request is received, the command stays idle, leaving the processor free for other duties. Similarly, the sender "sends" to the client the measurements acquired by the control loop when a command requires it. The acquisition and control-loop thread performs the data acquisition and closed-loop control of the process. On the other side, the client application also implements the transmission layer needed to exchange data with the server (Sender and Receiver threads). A third task is the rendering of the information to the final users.

![Figure 2: Remote control of a physical device through the Internet](image)

This framework uses a novelty approach to make the creation process of the experimentation resources in an easier way, which relies on the use of two software tools especially adequate for developing these experimentation resources: LabView and EJS. The approach is based on the creation of generic communication modules both in the client and the server sides. On the client-side, a Java library called jil.jar with a generic communication interface has been created. By this class the TCP protocol is hidden to users and simple Java classes/methods are provided to set up the connections. This library can be easily integrated into EJS programs to dialog with the server. Similarly, on the server-side, a LabVIEW executable program called JiL Server operates as a middleware communication layer between the client and the plant. Thus, developers are only required to create a local control Virtual Instrument (VI) in LabView that performs the acquisition and the closed-loop control of the plant. More information about this approach can be found in the literature (e.g. Vargas et al., 2009).
E-learning Resources (Complementary Web Facilities) Implementation

Urban-Woldron (2009) found that, in spite of the advances in computer based simulations (and in remote real experimentation), few works have been made to study the impact of different implementation methods of digital distance learning objects, which is a fundamental topic that teachers have to confront. VLs and RLs do not provide by themselves all the convenient resources for distance teaching/learning of students with all the implications that this methodology involves. Specifically, students must carry out their practical activities in an autonomous way and therefore, complementary Web based resources to the virtual and remote labs should be included. For this reason, all the VLs and RLs in this framework should not only present a description of the phenomena under study and of the didactical setup of the experiment for remote experimentation but also the tasks protocol they must follow to achieve the proposed goals. Moreover, a laboratory report the instructors would correct must be prepared by the students with the data collected during the simulated and real experimentation. Thus, a second key aspect to be addressed is the development of a Web platform that offers to students a personal online workspace and supports their learning process with the previous (and others) resources.

This e-learning platform organizes the access of users to available experimentation modules and simplifies the organization of user groups. It should also be able to offer notification services by email, instant messaging inside the online portal, news, forums, etc. allowing the interaction and the collaboration among students (and teachers/students).

This framework contains within the web portal all the necessary theoretical documentation like practical guides, tasks protocols, instructions manuals or any other kind of information needed to satisfactorily perform a remote experimentation session in an autonomous way.

The LMS could also suggest or impose a sequence of tasks or activities that students must carry out during an experimental session. The tasks can be of two types: Firstly, the tasks which students must carry out before performing the experiments in the real plant. This work should be done with a GUI that allows students to work in simulation mode. The aim of this first step is to get an adequate previous insight about the process. This way, students will reduce the time spent in the activities that work over the real plant. The access in remote mode should not be allowed until the student has completed the tasks in simulation mode. Once the student’s work in simulation mode has been evaluated by the teaching staff, the access in remote mode can be granted.

Another important task that must be taken into account is the management of students and their assessments as well as the uploading of reports and the tracking of them. Also, a personal online file repository for students where the data collected during their experimentation sessions is stored.

Finally, an automatic booking system must be included in the e-learning platform to schedule the access to the physical resources of the laboratory for the RLs can only be
used by one person at the same time. Therefore, a special application must be created to take care about the scheduling of these hardware resources. Some LMS also include booking systems that can be adapted and used for this purpose.

At the end of the development process, both kinds of resources are integrated to produce the Web environment. Moodle, a free LMS e-learning platform that offers all the necessary tools to cover the implementation requirements mentioned above as well as some additional interesting features, is used in this framework.

A framework instantiation example: Automatlabs

This section presents an example of application of the framework previously detailed to a university course about automatic and control.

The Department of Computer Science and Automatic Control of the UNED has been using VLs and RLs in the last years to give response to the demand from students who have difficulties to attend the classes in the academic centres. By means of these tools students have the possibility to have a first direct contact with the available systems: coupled three-tanks system, a temperature control system and a direct current servo-motor. The previous virtual and remote control laboratories can be appreciated in the left part of Figure 3. The upper picture shows the three-tanks system, a MIMO system where liquid level control experiences can be carried out. Multivariable control concepts can be studied and put into practice using this laboratory. The one in the middle shows the DC Motor, a SISO system that allows studying the dynamic behavior in speed and position of a motor fed by a direct current source. Finally, the bottom one depicts the Heat-flow system that allows performing practical experiences on systems with transport delays.

Every lab has two working modes: virtual (based on a mathematical model of the process) and remote (which access to the real plant). The GUIs are divided into two parts. The left part contains a graphical representation of the plant and a control panel used to define different system parameters. The virtual representation has been developed by copying the actual hardware. Thus, any variation of the system state during the simulation will be automatically represented over the virtual scheme. On the other and, when a user works in remote mode, this virtual representation is replaced by video images sent from the server. In this working mode, an augmented reality option is offered (Heatflow remote lab in Figure 3) and so the virtual representation of the process can be overlapped with the video image.
Figure 3: AutomatLabs web page and its online resources.

Figure 3 also shows the main page of the AutomatLabs portal listing all the 3 experimental blocks integrated into the Moodle portal. Each experimental block provides to students all the resources they may need to perform the online experimentation by themselves and they always follow the same structure: first link (blue line) opens the related documentation, protocol tasks, etc.; second link (red lines) opens the corresponding Java applet with the VL and RL (shown at the left of that same figure); third and forth links direct towards the files repositories where the data collected during the virtual and remote experimentation are stored, respectively; and finally, the last link from each experimental block opens the submission application to let students send their laboratory report to the instructors.

AutomatLabs uses a custom made booking system but there are free Moodle blocks such as rmbs5 that can be used instead. Moodle allows interaction among students (and between students and professors) by means of instant messages or forums (as long as the instructors have enabled these resources). Theoretical tests can be defined to evaluate students’ knowledge after reading the provided documentation and before allowing his access to the experimentation resources (the EJS Java applets). Instructors can also use Moodle to fix deadlines to perform the previous activities and these events become visible in calendars inside the e-learning platform for all the students.
Conclusions

This work presented a general framework which can be applied to any technical or scientific course that needs to provide experimentation as a complement to the theory lessons and offered an example of its implementation with AutomatLabs, a network of virtual and remote laboratories.

The proposed framework uses Java applets made with EJS, LabView to control the remote hardware, and a free LMS (Moodle) that provides and/or supports all the resources students may need: the virtual and remote laboratories, the documentation, the protocol tasks, the repository to store the files with the data obtained from the experimentation, an application to submit the laboratory reports prepared by the students, a booking system, and communication channels between students and instructors. The VLs and RLs provide students with the necessary tools to experiment with different systems and put into practice the theoretical lessons learnt from the documentation. This can be easily done in an autonomous way following the tasks protocol prepared by the instructors. Files with the images or numeric data obtained during the experimentation sessions are sent via FTP to the server and get stored separately for the different laboratories in each student’s files repositories. A booking system can also be integrated in the e-learning platform to take care about the scheduling of the hardware used by the RLs. Finally, communication channels such as forums and instant messaging are easily added thanks to Moodle. The final result is a framework that allows creating online portals where scientific students can perform their experimentation sessions at distance and in an autonomous way.

AutomatLabs is an example of application of this framework to a university course about automatic control and offers to students three virtual and remote laboratories along with all the other resources and tools described above.

Our current work is focused on two main lines: 1) remove the necessity of the FTP server to send the files with the collected data or images and 2) remove the use of a custom made booking system. The first goal can be achieved creating a Java library in charge of the communication with Moodle’s files submission application. The second one could be achieved making some changes to one of the previously mentioned booking system Moodle blocks.

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Improving the Learning Process in Statistical Decision-Making Laboratory

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Abstract: Statistics has been traditionally a difficult subject to teach and learn. Even the students with good mathematical skills may have problems in understanding the main principles of randomness, distribution functions and statistical significance. Additionally, it is not strange that students which have a good understanding about probability theory does not know how to use it in the statistical problem (i.e. once a random sample has been obtained, and the aim is to infer the values of parameters or distribution functions which better model the obtained data, in order to make decisions based in this information). This paper proposes a work in progress to improve the student understanding and involving in the process of statistical decision making, participating in a statistical decision making laboratory. The method is based in the following principles:

• The use of real economic data in order to predict the behavior of economic indexes, allowing the students to compare the real results with the results of the laboratory work. This comparison should be realized in a formal way, using decision theory principles (hypothesis test methodology).

• The use of the same statistical tools learned in the course in order to analyze and compare the results presented by the students. That is to say, if the numeric results from different students or student groups are very sparse, this fact perhaps indicates a poor work definition by the teacher. If the results obtained are very homogeneous but are far from the real world results, this perhaps indicates a common basic problem in the presentation of the theory and the laboratory work to the students. This is an important point, since the students use the tools used in the laboratory to evaluate the performance of their laboratory results, and to propose improvements, which is a clear motivation point.
Introduction

Statistics has an important role in the curricula of Telecommunication Engineering students, and its importance is twofold:

- The statistical tools have a direct application in Telecommunication Engineering subjects, such as Detection Theory, Communication Theory, etc.
- All Telecommunication Engineering students have some subjects related to general Enterprise management and technology management, and quantitative (statistical) analysis tools are necessary.

However, the teaching of statistics in Telecommunication Engineering curricula has been traditionally a very difficult challenge. Engineering students have a good preparation in probability theory (the formal models for uncertainty before data are collected), but they experience serious difficulty in dealing with statistical inference (that is to say, to extract information about facts related to populations using a limited random sample of data from this population). However, Statistics is a very important tool and should be clearly understood and assimilated by Telecommunication Engineering students.

Structure of the Statistical Decision-Making Laboratory

The Statistical Decision-Making Laboratory is currently designed as a case-study laboratory. It is divided into six modules, which are (Newbold, Carlson & Thorne, (2008); Law & Kelton, (2000)):

1. **Descriptive Statistics Module.** In this module the concepts of data grouping, frequency tables, graphs, central trend measures and dispersion measures are introduced.
2. **Time Series Analysis Module.** In this module the students learn to construct and interpret the additive models of time series (trend, seasonal, cyclic components and residual component).
3. **Estimation Theory Module.** The main objective of this module is that the students learn to obtain estimators of distribution parameters, and to associate and interpret the corresponding confidence intervals of these estimators. The adjustment of a candidate distribution function to a data set is also considered.
4. **Decision Theory Module.** This module considers the design of hypothesis tests, for one parameter and two parameters.
5. **Analysis of Variance Module.** In this module the student designs one way and two way ANOVA tests.
6. **Simulation module.** Finally, in this module, the main steps of the design of complex system simulators are presented. The statistical analysis of performance parameters obtained by simulation is also presented.

In all modules, the students must consider a set of synthetically generated data, and they must apply the techniques presented in the theoretical sessions in order to obtain quantitative measures to support a specific decision concerning a real problem based in a case of study. They resume their solution and decision in a final report for each module.
Also, in all modules, students use commercial statistical software packages in order to treat the data sets and obtain the statistical measures used to support their decisions.

**Some problems found**

Taking into account the student surveys and informal interviews with the laboratory students, carried out over the past two years, these are the main problems found so far with the ideas and concepts presented and current implementation of the Statistical Decision-Making Laboratory:

1. The data sets used in the laboratory are not representative of real economic data set. In the current implementation of the laboratory, the data used are synthetically generated, only for academic purposes, and they do not represent real economic data.

2. In some cases, it is difficult to relate the statistical results with its adequate real-world interpretation. This is a consequence of the previous problem. For instance, the result of an hypothesis test “Reject the null hypothesis $H_0$” using non-real world data are difficult to interpret by the student, which in turn causes a lack of assimilation of the main concepts and their applicability.

3. The students ask for additional uses of the statistical tools presented in the Statistical Decision-Making Laboratory to decision problems other than economical ones. The main focus of the laboratory is to present examples related to economics and enterprise problems. The students demand a deeper presentation of the wide applicability of the methods presented in the laboratory.

**Changes proposal**

The problems stated in the previous section have served as guidelines to propose some important changes in the design of the Statistical Decision-Making Laboratory. These changes are briefly explained in the following paragraphs.

**Use of real economic data**

It is considered the use of real economic data, in order to predict the behavior of economic indexes, allowing the students and the teacher to compare the real results of the methods with the results of the laboratory work. This comparison should be realized in a formal way, using decision theory principles (hypothesis test methodology).

For instance, the National Statistics Institute in Spain (2011) has a lot of data sets concerning all economic activities in Spain and it also computes and maintains a lot of economical indexes used as a reference by many activity sectors in Spain.

In the six modules of the laboratory, the data sets used will be modified, employing new data sets taken directly from the National Statistics Institute of Spain. Using these data, the students, for instance in Module 2 (Time Series Analysis), can compute a determined prediction of an economic magnitude of indexes employing the time series analysis tools presented in that Module of the Laboratory, and they can compare the predicted value...
with the real data when the corresponding data is available in the web, using also the hypothesis testing methods presented in the Module 4 of the Laboratory.

This also allows using up-to-date data sets, reflecting the current economical situation, each time the Decision-Making Laboratory is imparted, which will contribute to increase the student interest in the laboratory.

**Use of the Laboratory tools to evaluate Laboratory quality measures**

In order to show the students the wide scope of the statistical techniques presented in the laboratory, and to apply them to some other problem not taken from the economic world. We propose the use of the same statistical tools learned in the course in order to analyze and compare the results presented by the students. That is to say, if the numeric results from different students or student groups are very sparse, this fact perhaps indicates a poor work definition by the teacher. If the results obtained are very homogeneous but are far from the real world results, this perhaps indicates a common basic problem in the presentation of the theory and the laboratory work to the students. This is an important point, since the students use the tools used in the laboratory to evaluate the performance of their laboratory results, and to propose improvements, which is a clear motivation point.

The statistical tools presented may also be used to compare some measurements taken from the students when they perform the old version of the laboratory problems and the new ones, the first course when the new version of the laboratory is used, converting this in a new additional module (Module 7) of the laboratory.

To be specific, let us suppose that two different versions of the Estimation Theory module (the old version and the new version) are followed by two different set of student groups. The students measure the time they employ in solving that module and set a score related to some qualitative measure of the self-learning and satisfaction encountered with each module.

The last Module (new Module 7 of the Laboratory) will consist on the realizing a statistical test to evaluate if there are substantial differences in the times employed in following the exercises of the modules, and the qualitative self-learning and satisfaction measurement. Two possible statistical test to be employed are (Hogg & Tanis (2001)), (Newbold, Carlson & Thorne, (2008)), (Samuels, Witmer & Schaffner, (2011)):

1. Sign test.

We consider, as an example, the use of the sign test.
Sign test

As an example, let us comment how the sign test should be employed. The sign test is a nonparametric test that can be used to compare two paired samples. It is very flexible in application and is especially simple to use and understand.

The sign test is based on the differences of the simple paired values. The only information used by the sign test is the sign (positive or negative) of each difference. If the differences are preponderantly of one sign, this is taken as evidence for the alternative hypothesis. The following example illustrates the use of this test in the Statistical Decision-Making Laboratory.

The test could, for instance, be used to accept or reject the null hypothesis that the time employed in the old and new versions of the modules of the laboratory are the same versus the alternative hypothesis that the times are different, or to test the null hypothesis that the satisfaction with the old and new versions of the laboratory are the same versus the alternative hypothesis that they are different, or that the new version is more satisfactory for the student that the old one.

For instance, let us suppose that there are 11 laboratory groups and that they first follow the old version of the laboratory in one module and then they follow the new one in the same module. The next table shows the times employed by the groups, in minutes.

<table>
<thead>
<tr>
<th>Group number</th>
<th>Time in old module</th>
<th>Time in new module</th>
<th>Sign of the difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>139</td>
<td>120</td>
<td>+</td>
</tr>
<tr>
<td>2</td>
<td>125</td>
<td>138</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>128</td>
<td>118</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>137</td>
<td>119</td>
<td>+</td>
</tr>
<tr>
<td>5</td>
<td>183</td>
<td>146</td>
<td>+</td>
</tr>
<tr>
<td>6</td>
<td>126</td>
<td>111</td>
<td>+</td>
</tr>
<tr>
<td>7</td>
<td>123</td>
<td>110</td>
<td>+</td>
</tr>
<tr>
<td>8</td>
<td>125</td>
<td>136</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>153</td>
<td>148</td>
<td>+</td>
</tr>
<tr>
<td>10</td>
<td>119</td>
<td>108</td>
<td>+</td>
</tr>
<tr>
<td>11</td>
<td>150</td>
<td>135</td>
<td>+</td>
</tr>
</tbody>
</table>

In this example the null hypothesis is:

\( H_0: \) The time employed by the groups in following the old and new version of the module is the same. And the alternative hypothesis is:

\( H_1: \) The time employed by the groups in following the old version is larger than the time for the new version.

The first step is to determine the following counts:

\( N^+ = \) Number of positive differences

\( N^- = \) Number of negative differences
In this data set (see previous table) we have

\[ N^+ = 9 \]
\[ N^- = 2 \]

Let \( p \) represent the probability that a time difference will be positive. If the null hypothesis is true, then \( p = 0.5 \). Thus, the null distribution of \( N^+ \) is a binomial with parameters \( n = 11 \) and \( p = 0.5 \).

Let us assume a significance level of 0.05 (5%). The \( p \)-value for the test is the probability of getting 9 or more positive differences if \( p = 0.5 \). This is the probability that a binomial random variable with \( n = 11 \) and \( p = 0.5 \) will be greater than or equal to 9. Using the binomial formula or the binomial tables, we find that this probability is 0.03272. This value is less than 0.05, so there is significant statistical evidence for rejecting null hypothesis \( H_0 \) and therefore, for accepting \( H_1 \), the alternative hypothesis that time employed in the old version of the module is greater the time employed in the old one.

**Some comments**

The previous example would be a part of the work of a new module, to be implemented in this academic course, in which the students use the laboratory tools in order to statistically evaluate aspects of its own self-learning process. This has a twofold effect:

1. The students apply the statistical tools learned in the laboratory to non-economic data.
2. The students increase their motivation since they are self-evaluating their own learning process.

**Conclusions**

This paper presents some improvements in an Statistical Decision-Making Laboratory in a Telecommunication Engineering School. Starting from the fact that statistics is a difficult subject to assimilate from the students, and taking into account the student feedback from surveys and informal interviews during the past two years, we have proposed the following improvements in the laboratory design:

- The use of economical real data coming from the National Statistics Institute of Spain.
- The introduction of a final module designed to use the statistical techniques presented in the Laboratory to analyze some aspect of the Laboratory quality. This is a clear factor of student motivation, and also gives answer to the student asking of applying the laboratory tools to problems different than economic ones.
References


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Low cost 3D Gesture based interface use for engineering lecturing

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Abstract: This paper set sup the basis to build experiment lectures using low cost sensors to track lecturer gestures for several types of typical engineering lectures, and to design a user-based study to collect the feedback from students and teachers about the use of such technologies in undergraduate engineering courses, in order to draw some initial conclusions on the acceptability of this kind of interactions in the classroom.

Introduction

According to Eskicioglu and Kopec (2003) the key elements in an ideal multimedia-enabled classroom are networked computers, storage devices, printers, scanners, LCD projectors, electronic whiteboard, and digital cameras and camcorders. The use of multimedia-enabled classrooms is specially tailored for some kind of lectures or teaching and learning experiences, although it is not appropriate for some others. In this paper we will focus on the design and use of new hardware to support engineering lecturing, with its special constraints related to mathematical/logical complexity of the exposition, need to link real (physical) and abstract (models) objects and constructive/practical approach, needing to make the student not only capable of understanding concepts but also of actively using described theory and procedures to build effective solutions to engineering problems.

The two main practical approximations to give engineering lectures with complex mathematical content are the use of chalk blackboards and standard digital presentation tools ("Powerpoint® presentations"). Both methods are clearly focused on the presentation of theoretical information, covering the need for formal presentation of mathematical and logical concepts, but they are not so good at the presentation of links between reality and models, and on the definition of procedures to use the theoretical information (but in reduced applications addressed in laboratories/problem solving sessions). Near future use of virtual reality (with virtual objects) and other technologies in the classroom may change the approach in this kind of lecture, enabling for a more
complete understanding of not only the concepts but also their applications. Additionally, digital presentations tend to accelerate the lecture pace and therefore reduces student capability to follow the mathematical derivations, while blackboard-based lectures have several disadvantages: real time mathematical derivations are more error prone; readability depends on instructor tidiness and handwriting legibility; and lecturer position is less comfortable to obtain feedback on students’ reactions.

In this work in progress paper we are focusing in a key element enabling interactions with virtual objects, which is the definition of input systems to control them. The main sensors studied in this paper are low cost 3D vision sensors such as Microsoft® Kinect. The idea behind this research is enabling a natural interaction with virtual/abstract objects in presentations (equations, circuits, ...), and studying the effects in some kind of lectures. The objective is defining lecturing support tools to enable a presentation with at least all the advantages of a blackboard but mitigating their problems.

Next figure shows the concept of operation of the deployed lecturing support system, comprising a Kinect® Sensor, a controller computer with adequate software, and an electronic chalkboard.

![Figure 1: Kinect controlled presentation and virtual object manipulation concept](image)

The paper does not pretend to define a general framework for this kind of interaction, but is rather focused on the initial stages of this definition: we will use a reduced set of control gestures, focus on a defined problem (aiding the lecturer in a highly theoretical presentation), and define the method to draw initial conclusions on the acceptability of this kind of interactions in the classroom.

In section 2, the enabling technologies are described, and especially with respect to the kind of gestures which can be recognized. In section 3, the paper describes the basis to design a set of gestures to allow a rich and natural interaction with displayed content. In this section, concepts to enable enhanced interactivity with virtual objects and representations, potentially usable in other areas of application (such as circuit analysis, mechanical or architectural description of real objects, ...) will be described. Section 4 describes the basis to build an experiment lecture, and designs a user-based study to
collect the feedback from students and teachers about the use of such technologies in undergraduate engineering courses. Finally, section 5 is devoted to conclusions for the paper.

3D body tracking interfaces description

Serious gaming, aimed to the application of gaming related methods/hardware to other applications such as simulation, virtual reality gaming, sensors, imaging, etc. is a novel discipline. Gaming industry is a key technological driver for the definition of new ways of interaction with computers, specially with regards to low cost general public applications. For instance, Microsoft® Kinect and related technologies (such as PrimeSense® Sensors), provide the capability to perform body tracking from a series of images. The availability of software libraries such Microsoft Kinect SDK (currently in beta status in http://research.microsoft.com/en-us/um/redmond/projects/kinectsdk/) or the more mature OpenNI (http://www.openni.org/) framework to exploit this information from computers, in conjunction with hardware drivers for this kind of devices, makes possible to use them as computer control/input devices. Both Kinect (described in Engineering & Technology (2011)) and PrimaSense Sensors consists of a pair of visible and IR cameras that capture both 2D and 3D representations of the gamer directly in front of the device. Since an IR camera requires an IR source to generate a depth image, an emitter is mounted next to the colour and depth camera sensors. The entire controller is mounted on a motorised pan/tilt platform. Also, in Kinect, the array of four microphones lined along the bottom panel may be used to control the computer using voice commands. An example of the processing available through the OpenNI library can be seen in next images. Figures 2 is formed of captures of the visible and depth cameras for a given time instant, with higher intensity meaning shorter depth and darker zones meaning greater depth.

![Figure 2: Visible and depth camera image](image)

The system is able to derive a body skeleton representation, as can be seen in figure 3, where in blue are the images detected as a human body while the set of lines in yellow represent the different skeleton features in two different instants. As the user moves, the corresponding skeleton representation follows its movements. As can be seen, it is a simplified representation of the body comprising: head position; arms, composed as the connection of hands, elbows and shoulders; body, defined in a plane with four points; and legs, including knees and feet.
Figure 2: Tracking skeleton images

There are some important limitations of this representation. There is no knowledge of the direction being observed by the lecturer, which may be of interest to provide feedback on user interactions over virtual objects. Additionally, the search for a body-like structure in the image may lead to extraneous detection artefacts when the user takes real physical objects, such as the set of papers in the right image of figure 3.

“Actions” may be derived from skeleton movements. PrimeSense provides, in addition to PrimeSense Sensor drivers, a middleware called NITE performing user identification, feature detection, and basic gesture recognition using the depth image from the sensor. There is another software library, called FAAST (described in E. A. Suma et al (2011)), which interfaces directly with OpenNI/NITE to access this information and performs additional high-level gesture recognition for generating events based on the user’s actions. In contrast to articulated skeleton data, actions are more complicated since they require inferring meaning from the user’s pose and their movements over time. Any of the actions computed in FAAST (see the complete list of the 36 actions currently defined in http://projects.ict.usc.edu/mxr/faast/), as well as the basic actions from NITE, can be bound to virtual keyboard or mouse commands that are sent to the actively selected window. Furthermore, users can customize the bindings and sensitivity for these actions at run-time, through the definition of thresholds for action detection, thus providing flexible input that can easily be adjusted according to the individual user’s body type and contextual preferences. The initial objective of this library was providing methods to enable controlling any PC game through Kinect, through the appropriate bindings.

Design of 3D Gestures

The key driver in the design of a new support system for lecturing is the usability of the system for the lecturer, and the natural integration in the class workflow for students. Traditionally, as described in J. Nielsen (1993), usability has been associated with a number of attributes making usability a measurable quantity that can be evaluated quantitatively and compared:

- Learnability: The use of any new system involves a learning curve. In our case, the use of natural and meaningful gestures for presentation control is key to increase learnability, especially as one of the main objectives is deriving virtual object manipulation procedures.
- Efficiency: A way to quantitatively assess the efficiency is to measure the time it takes to make a series of specific tasks, for a user who has previously learned to
operate the system. An efficient control interface will stay out of the lecturer way, without measurable delays in the presentation.

- Memory load: The use of the system should be easy to remember after a period of disuse, so that the user does not need to relearn the system again. Again, it is enhanced if the design and organization of the gestures/actions seems "natural" for the user. One possible way to measure this attribute is evaluate sporadic use of the system for some users.

- Errors: The system must be designed so that users commit fewer errors when using it, and that the number of errors of importance is minimized. Also, the system must ensure that the recovery or going back to be as easy as possible. In a gestural interface it is clear in order to reduce errors it is important to define a set of pretty different actions so that the sensors do not confuse them.

- Satisfaction of use: It is a subjective measure that quantifies how nice and pleasant it is for the user to use the system. Therefore, subjective measures of satisfaction are often performed by asking directly to users, i.e. conducting surveys with questions related to user satisfaction in using the system. In our case, there is a key element in this satisfaction not covered by previous concepts, which is fatigue. Using a body tracking gestural interface may involve performing gestures with arms (or legs) for sustained time intervals, which can be tiring. Therefore, this aspect must be taken into account when defining the gestures to be used, as described in Y. Kim et al. (2011).

All previous concepts, in the definition of a system for lecturing based on 3D gesture recognition, lead to the following set of requirements for our deployment:

- There is a need to design a reduced set of gestures
- Gestures should be natural, if possible related with real world actions
- Gestures must be comfortable for the user
- Gestures must not interfere with lecturing by not looking clumsy or being culturally problematic
- Gestures must be easily identified and distinguished by the system
- Gestures must be not usually performed during normal movement of a lecturer, in order to avoid false detection of orders driving to changes in the presentation. In order to avoid problems during certain time intervals, gesture interface might be off for long periods and only recognize gestures when reinitiated by user.
- There should be specific 3D gestures for certain kinds of interactions with virtual objects as certain operations with equations, circuits, ... See for instance [http://www.algebratouch.com/](http://www.algebratouch.com/) for a touch based interface covering in a basic manner some of the potential interactions that could be described for basic algebraic manipulations.
- Due to coverage limitations of current body tracking systems, there is the need to confine lecturer movements to a part of the stage.

From all the potential actions detected by FAAST, only a few seemed natural, comfortable and not clumsy or ridiculous, those related to movement of hands and arms. Jumping, swiping or lean movements were discarded for not being compatible with previous
requirements. Other movements, as turning or walking were also discarded due to the facility to perform those movements during a lecture. The usable gestures are:

- Lef_arm_forwards t/right_arm_forwards
- Left_arm_down /right_arm_down
- Left_arm_up /right_arm_up
- Left_arm_out /right_arm_out
- Circle
- Wave

In order to maintain a low error rate we must not distinguish between both hands/arms gestures. One gesture (possibly circle) must be reserved for “Undo” action, which must be always present. Additionally, several typical virtual object manipulations must be defined in each domain of application. For instance, in mathematical derivations a list of basic linear algebraic manipulations might be:

1. Evaluation of any parentheses, exponents, multiplications, divisions, additions, and subtractions in the usual order of operations, using associative and distributive properties properly.
2. Combination of like terms: This means adding or subtracting variables of the same kind. For instance the expression $2x + 4x$ simplifies to $6x$. The expression $13 - 7 + 3$ simplifies to 9.
3. Addition or subtraction of any value to both sides of the equation.
4. Division of both sides of the equation by any non-zero number.

Some of those operations may need additional parameters, which could be provided by other means (for instance, the insertion of numbers by means of virtual sliders). In addition, selection of terms for operation should be enabled, and a grammar for the ordered application of manipulations defined. In this case, creation of initial equation or mathematical expression is the most complex operation, involving for the definition of a complex set of ordered actions. Another example would be Laplace circuit analysis. There are several typical operations to be performed:

1. Include new impedance
2. Include new Input generator
3. Link generators and impedances
4. Select impedance branch
5. Calculate impedance of selected branch
6. Calculate Laplace transform of Input Generator
7. Calculate Output (Voltage or Current) in given branch or between two circuit knots.
8. Derive Kirchoff equations for circuit
9. ...

The application of typical procedures to each domain rapidly grows. This leads to the need to group actions, so that we use “action” sentences composed of several related gestures, so that the meaning of each specific gesture changes along time. For instance, including a
new impedance would demand defining if it is a capacitor, a resistor or a coil. Then, we would need to define its value, or provide an algebraic name to it. Then, several ordered gestures translate to several key bindings and to the ordered manipulation of the virtual objects.

Finally it is important to note along a lecture it is usual to have the need for several modes of manipulation associated to different domains. For instance, in circuit analysis we would need to build and analyse the circuit, but possibly we would need to perform algebraic operations over the operations derived. A method to change the mode of manipulation shall also be defined.

**Experimental deployment and data analysis procedure**

The next key point is the description of a reduced set of lessons and related modes of operations, and the associated feedback collection procedure. Several types of lectures will be implemented, with different domains of applications:

- Theoretical, highly mathematical, lesson on circuit theory.
- Problem solving session on circuit theory.
- Management course use case session. In this case, virtual objects are much more simplified, and simple interactions with slides and multimedia objects are the only need.

The evaluation of the system for educational purposes is divided into two phases: A first usability focused phase with the lecturers, a second phase where the previously described lessons are implemented, where both lecturer and students feedback are to be obtained.

**Lecturer feedback**

First phase evaluation of the concepts will follow a typical usability evaluation paradigm, adapted to our problem. Here the user is the lecturer. Usability testing is performed basically following two approaches:

1. Expert testing, without real user involvement, such as the cognitive walkthrough or the use of an agreed set of usability heuristics [13].
2. Real user tests. These consist of structured tests observing and asking lecturers using the real devices and applications. The main points to consider are:
   - The main objective in the improvement of the usability of the product or service.
   - The test must be structured on specific task and objectives (sequences of actions/gestures).
   - The users must perform real tasks in a presentation (from slides passing to virtual object interaction and mathematical derivations).
   - The actions and comments from the users should be recorded (both audio and video).

After test completion, an analysis of the collected data must be performed, in order to diagnose potential usability problems and to recommend correction actions. To achieve
this, an analysis of the user record must be performed, in order to obtain objective measures. Besides the objective measures, it is also important to collect subjective measures of the user satisfaction. A survey over the users view on the system could contain questions such as: Use satisfaction; Use difficulty; Utility; Learning facility; Error recovery facility; ...

Classroom deployment feedback

After each of the sessions, the lecturer will provide its subjective impression on the adequacy of those technologies to the particular lesson type. It will be recorded through a questionnaire comprising items identifying time and difficulty needed to prepare the session, comfort during the lecture, ... In addition, the same lesson, using classical procedures, will be imparted to a control group, and objective measures as time necessary to finish the lesson will be also derived. Several different lecturers will use the described deployment for a same lesson, and their distinct opinions and performance measures analysed.

The students will also provide their subjective impression on the adequacy of those technologies to the particular lesson type using an adequate survey. Regarding efficiency of the technologies, an objective exercise to assess the students learning performance will be performed at the end of each of the sessions.

Conclusions

This work in progress is yet at its initial stages, so there are no clear conclusions yet on the applicability of this system. The following key aspects need to be addressed in the next steps of the research:

- Define domains of application related objects and manipulations.
- Link the described basic gestures and actions with manipulations of objects in a more formal way, by means of a simple and natural gesture based language, which should be similar across domains.
- Implementing a prototype system, using ad-hoc software for control of virtual objects.
- Define lesson contents, and prepare initial support material for it.
- Record lesson and obtain feedback data
- Analyse feedback and tune the system

In this research we will be investigating the limitations of our deployment. It is clear a lecturing system only based on this case of interaction would be difficult to operate, and surely a multimodal control method must be deployed, including additionally electronic inking procedures in chalkboard on in touch based interfaces, voice recognition and control procedures, or others.
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Assessing the ethical development of engineering undergraduates in the United States

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Abstract: Developing engineers must be aware that technological development and emerging global issues will require a keen sense of ethical responsibility and be prepared to reason through and act appropriately on the ethical dilemmas they will experience as professionals. This investigation evaluated different institutional approaches for ethics education with a goal of better preparing students to be ethical professionals. The project included visiting 19 diverse partner institutions and collecting data from nearly 150 faculty/administrators and over 4000 engineering undergraduates. Data were used to identify variables that have the most positive impact on students’ ethical development. Findings suggest that the number and type of co-curricular experiences have an important influence on ethical development, that students with higher levels of ethical reasoning are less likely to be satisfied ethics instruction, and that the institutional culture made a difference on how students behaved and how they articulated concepts of ethics.

Introduction and Context

The development of future technologies and emerging global issues will require a keen sense of ethical and social implications (NAE, 2003; NAE 2004). Therefore, developing engineers must not only be aware of existing national and international ethical standards, but must also be prepared to reason through and act appropriately on ethical dilemmas they will experience. This sentiment is echoed by Sheppard, et al. (2009), who argue that
as technology grows more complex and its effects on the world become harder to predict, the ethical issues faced by engineers also grow in complexity and uncertainty. However, research has shown that traditional institutional approaches used to develop these skills in engineering undergraduates might not be adequate (Bucciarelli, 2008; Drake, et al., 2005; Harding, et al., 2003). Professional engineers themselves have reported that their ethics education as undergraduates did little to prepare them for the ethical realities they face in their profession (McGinn, 2003). It was the intention of this investigation, the Student Engineering Ethical Development (SEED) project (http://www.engin.umich.edu/research/e3/index.html), to evaluate different institutional approaches for ethics education with a goal of better preparing students to be ethical professionals by determining how universities can improve their students’ ethical decisionmaking capabilities.

The SEED project is a cross-sectional assessment of the ethical development of engineering undergraduates in the United States. The project included identifying and visiting 19 diverse partner institutions from across the United States and collecting data from nearly 150 faculty and administrators and more than 4000 engineering undergraduates through interviews, focus groups, and an online survey. This approach allows for a general understanding of both the current state of engineering ethics education in the United States and relates key institutional approaches for covering ethics in the curriculum to a student’s ethical development.

**Research Questions**

The intention of this investigation was to evaluate different institutional approaches for ethics education by evaluating students’ ethical development. In other words, what are the explanatory variables within four major domains (formal curricular experiences, co-curricular experiences, student characteristics, and institutional culture) that affect our primary outcome variable (ethical development) as measured using three constructs – knowledge of ethics, ethical reasoning, and ethical behavior?

If we can identify variables that have the most positive impact on students’ ethical development, institutions can adjust their programming to try to improve their students’ ethical decision-making capabilities. This will aid in preparing students to be ethical professionals ready to perform in an increasing complex and global environment.

**Theoretical Framework**

Our conceptual model of ethical development (adapted from Terenzini and Reason, 2005) consists of related but distinct domains affecting students’ engineering ethical development: Student Characteristics, Institutional Culture, and Individual Student Experiences (including Formal Curricular Experiences and Co-curricular Experiences) (Figure 1). Student Characteristics refers to student demographic and behavioral characteristics. Institutional Culture refers to the culture of the engineering school or department within the context of the institution as a whole, both of which influence student outcomes. The Individual Student Experience consists of the experiences of individual students in this investigation and includes students’ Formal Curricular
Experiences and Co-curricular Experiences. Finally, the model measures a students’ Ethical Development as three distinct outcomes: Knowledge of Ethics, Ethical Reasoning, and Ethical Behavior. Knowledge of Ethics refers to a student’s understanding of professional engineering codes of ethics and other rules governing ethical behavior; Ethical Reasoning refers to a students’ ability to apply reason when identifying ethical options to ethical dilemmas, and Ethical Behavior refers to student engagement in ethical and non-ethical behaviors.

Figure 1: Comprehensive model of a student’s ethical development during college (adapted from Terenzini & Reason, 2005)

Methodology

To holistically measure ethical development across the US, the research team identified a diverse group of 19 partner institutions from which to collect data. Institutions were selected from an initial set of potential partner institutions by categorizing all four-year degree-granting engineering programs into four categories based upon their Carnegie Classification (2011). Institutions in each category were then ranked according to the combined number of students majoring in civil, mechanical, and electrical engineering (traditional engineering disciplines). The final set of institutions was created by selecting institutions with the largest undergraduate engineering enrolment from each of the four categories and making adjustments to maximize both geographical diversity and diversity of institutional type. While enrolment in traditional engineering disciplines was used to select the partner institutions, engineering undergraduates of all majors were included in the study.

Institutions were visited between fall 2007 and spring 2010 to collect data to inform the design of our SEED survey and to better understand the institutional culture. These visits resulted in focus groups with 123 students and 110 faculty members and interviews with 36 senior level academic and student affairs administrators. For these visits, a random sample recruitment process was employed for the students, and a local campus liaison selected faculty and administrators either involved in ethics education or with knowledge of how ethics was included within the curriculum. Students and faculty completed a brief
anonymous questionnaire which allowed us to aggregate their demographic characteristics. Student participants reflected the demographics of engineering students nationwide, with two-thirds of the participants being male, 75% studying civil, mechanical, or electrical and computer engineering, and three-quarters being white. Faculty participants were similarly reflective of U.S. faculty demographics, with less than 20% being female and more than 90% being white.

Besides using site visits to inform our understanding of the institutional culture at each partner institution, data from the focus groups and interviews was also used to guide the development of our SEED survey. The analytic method differed from traditional qualitative methodology as we coded types of transcript data rather than focusing on discovering themes or drawing parallels or distinctions across institutional types. For example, with regards to formal curricular experiences, we coded three types of data:

- the types of activities affecting ethical development, for example, ethical case studies,
- the setting in which those activities were conducted, for example, within a capstone engineering course, and
- the pedagogical method by which those activities were conducted, for example, a case study presented by an actual participant in the case who asked students to reflect upon it and create their own ethically defensible solution.

From this analysis, the survey instrument was drafted and subsequently validated in three phases. First, we conducted several cognitive interviews in which students engaged in “think-aloud” responding during one-on-one interviews at two of our 19 partner institutions. This allowed us to gain an understanding of the way in which students interpreted specific items and to rephrase our item wording appropriately. Second, we held a focus group with other students from the two institutions to confirm the timing and length of the survey (administered in paper form) and to further establish clarity of instructions and survey items. Finally, the survey instrument was refined and administered online at a third partner institution. Our final online SEED instrument included more than 200 items and was comprised of the explanatory variables of our model as well as constructs comprising our outcome variable ethical development (Table 1). More information about survey construction is available in earlier papers by the authors (Holsapple et al, 2009; Sutkus et al, 2008).

Student responses to this survey were used to identify explanatory variables that have the most positive impact on students’ ethical development. This was determined by using a regression framework to test relationships between explanatory variables and our three measures of ethical development.

Findings and Conclusions

Our overarching goal is to identify and disseminate best practices for engineering ethics education in the United States. While the findings are U.S.-based, there are identifiable themes applicable to the international educational community. The size and scope of the project and subsequent data set make presenting a detailed analysis impossible given the
First, institutional culture made a difference on how students behaved and how they articulated concepts of ethics (Holsapple, et al., 2010). Therefore, institutions should establish and communicate clear behavioral expectations from the upper administration down through the faculty/staff and to the student body such that the culture of the institution is one that promotes ethical development. Problems will arise if the administration preaches ethical behavior and then faculty ignore, or worse yet, promote, academic dishonesty by classroom policies and procedures. Faculty who exhibit unprofessional behavior also provide an excuse for students to behave unethically.

Results indicate that the number and type of co-curricular (i.e. out of class) experiences have an important influence on ethical development (Burt, et al., 2011). We determined that when engineering students are involved in co-curricular experiences, they exhibited greater leadership skills were more thoughtful on ethical decisions, and could articulate at a basic level how involvement influenced development. However, both over-commitment
in activities and no involvement have been shown to lead to unethical behavior, so co-curricular involvement must be properly balanced with academic expectations.

Findings also suggest an inverse relationship between ethical reasoning and satisfaction with ethics education – students who have higher levels of ethical reasoning are less likely to be satisfied with their ethics instruction (Holsapple, et al., 2011). In fact, it appears that students in lower-level classes actually respond negatively to being overexposed to ethics curricula. This may suggest that students early in their engineering curriculum are not yet properly versed in the field to truly absorb and apply the information presented in ethics discussions. One possible explanation for the inverse relationship is that students who have higher levels of ethical reasoning are more likely to apply more nuanced approaches to ethical dilemmas. These students may be dissatisfied with ethics instruction that focuses on memorizing codes and rules rather than addressing complex areas of ethical dilemmas. This was reinforced by the qualitative data that revealed very little awareness by all groups (administrators, faculty and students) that ethics was a developmental issue.

Finally, for the three output variables, there was little correlation between academic dishonesty and reasoning or academic dishonesty and ethical knowledge. In other words, academic integrity could not be linked to higher ethical reasoning or ethical knowledge based on the measures used in this study. There is a mild positive correlation between ethical reasoning and knowledge. We found that students who were able to reason through ethical dilemmas based on the DIT2 did score higher on the ethics knowledge section of the assessment.

**Recommendations and Future Research**

Purposeful and meaningful engineering ethics education is not easy, but is necessary to prepare our graduates for the future of engineering, which will be more technologically advanced and integrated. We recommend establishing a common vocabulary for ethics across campus constituents and designing a curriculum that spreads ethics education across the duration of the degree program. However, the curriculum should focus on ethical decision-making at appropriate developmental levels. We also recommend promoting co-curricular involvement through service programs and professional organizations. Involving students in the right experiences can facilitate ethical growth.

Future research plans include analyzing the current SEED dataset to test subgroup differences (i.e. student characteristics such as race, gender, major, etc.) for relationships between input variables and ethical development. In addition, most analysis to date has been either qualitative or quantitative. A mixed methods approach of analyzing the data is currently underway and appears to be meaningful in building our understanding of engineering learning. Finally, a limitation of this holistic assessment was that data collection was cross-sectional. While cross-sectional data allows for correlational analysis of the relationships between students’ previous experiences and their current levels of ethical reasoning, a longitudinal analysis allows for insight into the potential causal relationships between curricular experiences and student outcomes. We hope to transition this investigation into a longitudinal study. Future data collection could also
include more information from primary sources (transcripts, syllabi, student artifacts, etc.) instead of relying on respondents’ self-reports.

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Engineering Ethics: An Exploration of the State of the Art

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Abstract: We present as a work in progress a qualitative meta-analysis of the engineering ethics literature, with a focus on the different ways researchers and educators conceive of engineering ethics. Our analysis includes textbooks with engineering ethics as a primary focus or where it is given other substantive treatment and journal articles seeking to define, analyze, or apply engineering ethics. Our goal is to help other engineering educators and researchers understand the various meanings and uses of engineering ethics.

Introduction

Although engineering ethics is by now a field worthy of serious attention by both engineers and philosophers, it remains a field in need of development, both in a sense of definition (i.e. what do we mean when we say “engineering ethics”?) and of scale (i.e. what is the range of kinds of examples that qualify as “engineering ethics”?). This has been the case for some time. In 1980, in one of the earliest attempts to identify the state of the field, an extensive bibliography appeared containing over 500 entries on “professional ethics and social responsibility in engineering” (Ladenson et al, 1980). But according to Davis (2005, p. xv), “only a few” of these entries could count as properly philosophical, and, “of those, only two explicitly discussed engineers.” What, then, could engineering ethics mean, if the works that represent it are not concerned with both engineering and ethics? The works in the Ladenson bibliography tend, according to Davis, to be “law cases, newspaper articles and empirical studies of one sort or another.” They address wrongdoings, legal issues, and professional responsibilities. They do not, in other words, represent the integration of the otherwise separate fields of engineering and ethics by showing what is philosophically important about engineering problems.

Our understanding of engineering ethics requires just such an integration. To be considered engineering ethics, properly understood, a work must present the way in which philosophical argument elucidates what is ethically important about engineering problems. Without demonstrating how ethical theory (in any of its forms) operationalizes
in the context of engineering we do not have integration of the two fields. For example, to say the decision to launch the space shuttle *Challenger* is an example of professional *engineering* wrongdoing requires only that we point to Robert Lund’s motivation for giving the launch approval being a manager’s motivation rather than an engineer’s. This shows at the very least that safety was not paramount in his decision, a violation of nearly every code of ethics ratified by professional engineering societies. But while this might help identify who is blameworthy, it does not elucidate the philosophical apparatus making it an *ethically* important violation, although it certainly is ethically important. A complete integration might, for example, also explain the special moral obligation an engineer has by virtue of being an informed and consenting party to the social contract that defines engineering as a profession. It would give reasons for why Lund’s decision to act as a manager rather than as an engineer was morally wrong, given its context in engineering and Lund’s existing moral obligations as a professional engineer.

### Research Questions

The purpose of this study is to assess the current state of the field of engineering ethics and to provide a sense of the state of the art. To accomplish this, our project’s central research question is the following: how are contemporary writers articulating the concept of engineering ethics? We phrase this question deliberately so it does not seek or expect a singular definition. Rather, our aim is to explore the plurality of uses people have made of engineering ethics. For example, we want to see what writers focus on once they decide that what they are doing is engineering ethics.

The value of a meta-analysis such as this, where a disparate field is collected and analyzed in one place is at least twofold: first educators have the resources of an entire field at their disposal, helping choose the appropriate materials for their course curricula; second, understanding the current scope of the field will help researchers design measurements and studies by showing what materials are available and how they differ from one another.

The exploration of this question is important to engineering education as our findings will provide a valuable framework for future researchers and educators looking to understand the field of engineering ethics at a glance.

### Methodology

Our analysis was guided by the landmark books in the field (Harris, Pritchard, Rabins, 2005; Fleddermann, 2008; Whitbeck, 1998; Martin & Schinzinger, 2004) as well as other common but less frequently cited books (Gunn & Vesilind, 2003). For journal articles, we were grateful to be able to make use of the very thorough collection of relevant essays by the philosopher Davis (2005). In this work Davis has already undertaken much of the labor involved in investigating, collecting, categorizing, and contextualizing what seem to be, in his opinion, the most important articles in the field up to about 2001. For the most recent decade we relied on traditional database search methods using relevant search terms, including but not limited to “ethics,” “engineering,” “morals,” “morality,” “professional,” “responsibility,” etc. We applied these terms to common engineering and
engineering-centric journals and to philosophy journals, both those generally geared toward ethics issues and otherwise. As a result, our preliminary analysis includes nearly 200 academic journal articles published since 1980, but those which have engineering ethics as their primary topic, rather than a point made in passing, number far fewer. We have paid particularly close attention to work published in *Journal of Engineering Education* and *Science and Engineering Ethics*.

The goal of our search was to find as many items on the topic of engineering ethics as we could. The goal of our analysis was to investigate the different ways in which the authors of these works conceptualize and present engineering ethics. For the purposes of this work-in-progress paper we will not attempt to describe or even categorize each item turned up in our search, but rather demonstrate the major ways in which engineering ethics is articulated or presented across the literature.

**Major Findings**

Books with engineering ethics as their primary subject matter are generally written in one of two forms: a student-oriented textbook, or a more theoretical treatise.

The majority of these are written in the orientation of a textbook, with the aim of providing useful materials or examples to students or teachers in the engineering disciplines interested in learning at least the basics of engineering ethics. Indeed, all of the landmark works mentioned above are specifically designed to be used as textbooks. For example, Schlossberg (1993, p. 3) begins by stating “this book is a practical guide to ethical decision making for practicing engineers and other in technologically oriented business and industry.” Whitbeck (1998), in particularly innovative approach (more so considering the year), says her book “is designed to be used with active learning classroom exercises and makes extensive use of the resources on the WWW Ethics Center for Engineering and Science [now onlineethics.org].” Nearly all of the other books referenced have explicitly similar aims (see Harris, Pritchard, Rabins, 1997; Harris, Pritchard, Rabins, 2005; Pinkus et al, 1997; Fleddermann, 2008; Humphreys, 1999; Flores, 1989; Martin & Schinzinger, 2004).

Generally, since engineering ethics textbooks describe their subject in many small pieces, making it more easily digestible by students coming to the subject for the first time, they also run the risk of not offering substantive philosophical justification for the ethical importance of each aspect mentioned. (See Compartmentalization below).

In contrast, several of the books on engineering ethics are written as treatises, by single authors, and contain extended treatments of their topic in a deeper, more philosophical, more “academic” sense. These books make no claims to be for students directly but are rather contributions to the field of engineering ethics theory, in the sense they aim to develop the body of knowledge associated with the field. Spier’s (2001) book, *Ethics, Tools, and the Engineer*, conveys a deep understanding of the moral importance of the engineer stemming from Spier’s own background in biotechnology. The danger, he says, is that “all tools can cause damage as well as benefit,” and our societies have to “come to terms with such instruments.” Spier considers at length the ways in which engineering has related to
tool making which has led to population growth which has led to increased risk of personal and emotional harm due to the dangers of highly dense populations. Along the way we get a clearer picture of ethical theory and the role it plays in the type of engineering progress Spier describes.

Similarly, *Thinking Like an Engineer* (Davis, 1998) is an extended and penetrating look into the moral mind of the engineer *qua* engineer. Davis’s approach is decidedly philosophical, and the book’s point of view—rather than being a practical guide for students—is a deeper meditation on what it means to be, and what is required by, an engineer in a moral sense. To give one example: in chapter four, Davis gives an analysis of the decision the launch the space shuttle *Challenger*, a case familiar to anyone who has studied engineering ethics since the late 1980s. But Davis’s analysis is deep, philosophical, and yet centered on the very essence of the moral stature of engineering. For other work, see (Catalano, 2006).

Since many of the frequently used and frequently cited books are textbooks, our analysis below examines several of the major features, foci, and methods of these works (and some of the dangers) as we try to understand how they formulate and communicate the concept of engineering ethics.

**Compartmentalization**

What has been both an advantage and a danger of the textbook format is that it allows for the books’ main topics to broken down to their components. The many books on engineering ethics composed in this style are organized, surely by a matter of pedagogical necessity, in a way that separates all the complex considerations that go into understanding ethically-important situations in engineering into their own sections. The result of this can be disjointedness, or the sense that these books do not give adequate attention to what makes each part a necessary component of the integration of ethics and engineering. During our analysis, while it was often easy to see which pieces authors seemed to think were part of engineering ethics, it was more difficult to determine exactly why they thought so. We were often left to infer on our own why they think these pieces, or these cases, or these particular issues are philosophically important, if we could at all.

For example, in the very commonly used classroom-oriented book *Engineering Ethics* (Fledermann, 2008), a good book in many senses and now appearing in a fourth edition, the table of contents indicates the following structure: 1) Introduction, 2) Professionalism and Codes of Ethics, 3) Understanding Ethical Problems, 4) Ethical Problem Solving Techniques, 5) Risk, Safety, and Accidents, 6) The Rights and Responsibilities of Engineers, 7) Ethical Issues in Engineering Practice, 8) Doing the Right Thing. The book keeps these sections compartmentalized, without much synthesis among them and without pointing out what makes these issues philosophically important. In understanding the state of the art of engineering ethics, it is important to understand this approach and the difference between this and the type of philosophical rigor applied to engineering problems as seen in the monographs by Davis, Spier, Catalano, and others.
Focus on Safety and Codes

Samuel Florman (2002) reminds us that "In the nineteenth century, Senator Thomas Hart Benton, arguing against legislation intended to reduce the risk of steamboat explosions, proclaimed that the proper way to tell if a boat was safe was to inquire personally as to whether the machinery was in good working order." Today, these days of non-regulation are gone, but the sense of ethics as an imperative not to harm—or in an engineering sense, to ensure safety—remains. Senator Benton's trust is replaced by codes of ethics, now ubiquitous among engineering societies, most of which lead with an imposition of a duty to "hold paramount the safety, health, and welfare of the public" (NSPE, 2011). Many works on engineering ethics focus on the engineer's responsibility to adhere to these codes, and some focus on this alone, as if engineering ethics has to do with nothing else. Humphreys (1999) for example, though it contains sections fitting categories below, is dominated by sections on proper project management, professional development, licensing and registration laws, the "engineers creed," disciplinary boundaries, reasonable safety, appropriate compensation procedures, and the fundamental canons. Flores (1989) presents a collection of articles looking at engineering ethics as a dimension of technical risk management. Flores (1982) develops a defense of the Monsanto Co., a producer of industrial chemical products, as the premier "ethical" company of the time. His evidence? Monsanto was among the “top six chemical producers in workplace safety” (p. 3). Why is it that a safety record makes Monsanto an ethical company? Flores does not say. Many books and articles focus on the importance of adherence to the codes of professional societies, both for legalistic reasons and, so it would seem, though less commonly, for moral reasons (examples of the latter: Davis, 1991, 2001, 2009, Harris, 2008).

Professional Responsibility

Professional responsibility describes those things engineers become tasked with when they become engineers. While acting ethically would be included, professional responsibility is broader, including, for example, the responsibilities that come along with a job title. These responsibilities are sometimes confused for ethical responsibilities and unless an author offers the philosophical justification for why a certain responsibility is ethically important, it is difficult to know whether it truly is, or whether it is a case of a non-moral responsibility going by the name of engineering ethics.

This confusion of professional responsibility, which appears in the literature, is similar to thinking of ethics in a legalistic sense. True professional responsibility (in the non-moral sense) might take the form of carrying out the many tasks or following the many rules or guidelines set for you by your engineering firm or your professional society, something which is actually well reflected (in a corporate sense) in Lockheed Martin's ethics training game, the Ethics Challenge (1997). Nearly all books surveyed mention the engineer's responsibility in one form or another. Harris, Pritchard, and Rabins (2005) have a nice chapter dedicated to responsibility in engineering in which they consider the nature of responsibility as well as common impediments engineers might encounter. Davis (1998) provides a detailed explanation for why engineers are morally responsible for the morally relevant aspects of their professional work.
Cases

Engineering being a verb, and this sense of action and engagement being ingrained in the very concept of engineering, educators have long used cases to bring to life examples of their otherwise more pedestrian lessons. This is true now more than ever, especially since the appearance of Harris, Pritchard, Rabins’s book *Engineering Ethics: Concepts and Cases* (2005). Treatments of cases might best be separated into two main types: those that simply offer (as a resource, aid, or guide) a series of cases presenting ethically-relevant scenarios from engineering practice (such as the many listed on onlineethics.org, 2011), and those that combine with their cases thoughtful exegeses, sometimes in relation with primers in ethical theory (see below) (such as Harris, Pritchard, Rabins, 2005; Schlossberger, 1993; Whitbeck, 1998). Humphreys (1999) provides cases from the NSPE board of ethical review, complete with their rulings and accompanying rationale. It should be said, though, that cases such as these meet our understanding of engineering ethics only when they include explanations of what makes them philosophically relevant. Not all engineering cases are ethically relevant, of course, and those that are require the highlighting of their ethical character.

Problem-Solving Methods and Formulae

Ethics in practice must be operationalized if it is to be of any use. Typically philosophers will reserve the word “morals” for the actual behavior that results from following one’s ethical beliefs. The process of choosing how to act in an ethically-relevant situation is referred to as moral decision making. While the study of moral decision making more properly falls under the purview of psychological research, rather than philosophy (Rest, 1999), the operationalization of ethics inherent in engineering practice means moral decision making is properly a part of engineering ethics.

Many of the works in our study describe problem solving methods for engineering ethics problems (whether they used the language of moral reasoning or not). Harris, Pritchard, Rabins (2005, p. 56) provide a “process of moral thinking.” Martin and Schinzinger (2004) have a useful chapter on moral reasoning and resolving ethical dilemmas. Fleddermann (2008) describes ethical problem solving techniques. Jonassen et al (2009) present a more research-oriented approach to problem solving in engineering ethics. There has been prominent work done in the field of psychology outlining the ways in which people might engage in moral decision making in the professions (Rest, 1999), but this work has yet to appear in the engineering ethics literature.

Primers in Ethical Theory

Many, though not all works in engineering ethics offer at least a primer in the basic ethical theories. As with cases, primers are often presented either by themselves—the more common approach—(see Fleddermann, 2008; Robinson et al, 2007; Whitbeck, 1998; Humphreys, 1999; Spier, 2001), or integrated with engineering examples (Harris, Pritchard, Rabins, 2005; Schlossberger, 1993). When works are authored or coauthored by ethicists, these sections do tend to be reflective of philosophical tradition and are likely
to be applied to engineering cases, showcasing the integration we have said is critical to the conception of engineering ethics.

Gunn and Vesilind (2003) utilize another method, perhaps best described as a combination of the others. The authors insert information boxes into a running fictional narrative, a story they say began as a novel and transformed into a textbook. The insertions take different forms, sometimes as primers in a particular ethical theory, sometimes simply posing a challenging question to the reader without the integration of philosophy, but always with some relevance to the narrative.

Engineering Ethics & Conclusions

The engineering ethics textbooks often communicate their conception of engineering ethics by breaking it down into its component parts, but in doing so they run the risk of losing the sense of integration that truly ties together these otherwise unrelated fields. Codes of ethics, for example, are certainly an important part of the complete picture of engineering ethics, but without understanding why professional codes hold moral weight with the professional engineer, we cannot truly understand the significance of engineering ethics. To explain any of these components adequately—components such as codes of ethics, the roles of risk and safety, the moral rights and responsibilities of engineers, identification of ethically-important issues, etc.—one must include a defense, specifically an explanation of what connects these components to ethical theory, or why these are philosophically (that is, ethically) relevant.

Often these cases are made in the extended treatments of the subject, what we have referred to as the treatises on engineering ethics. Though they number fewer than the textbooks, there are a number works that exemplify a deep interweaving of both ethical and engineering insight and the ways in which ethical theory can be put to work to resolve engineering problems. For examples, see (Catalano, 2006; Schlossberger, 1993; Doorn, 2009; Davis, 1998). Davis (1991) has made the case that having a code of ethics is, in part, what defines a profession and what establishes the moral status of the profession. “Without a professional code, an engineer could not object as an engineer. An engineer could, of course, still object ‘personally’ and refuse to do the job. But if he did, he would risk being replaced by an engineer who would not object. . . . His interests as an engineer would conflict with his interests as a person.” Engineers are benefited, universally, to the extent each follows the professional codes. And each engineer is obligated, ethically, to follow the codes in their entirety once the engineer accepts the benefits of being an engineer. Davis says, “the moral principle on which this argument primarily relies is the principle of fairness.”

Explaining the ethics of Robert Lund's decision to give his approval to launch the space shuttle *Challenger*, Davis says, “Since Lund voluntarily accepts the benefits of being an engineer (by claiming to be an engineer), he is morally obliged to follow the (morally permissible) convention that helps to make those benefits possible.” Lund’s actions are morally condemnable not because he violated the professional code of ethics, but because in doing so he showed disregard to the notion of fairness, to equal treatment of his fellow human beings, and to the importance of maintaining a system of fairness and reciprocity—
once one is established, as it is in a profession—in a social community. Though Lund might be blameworthy in other senses, too, this is why his decision is a study in engineering ethics. And Davis's integration of engineering process with philosophical argument exemplifies the meaningful insight which is crucial to engineering ethics, but which we found to be in danger of being left out of the compartmentalized, student-centered textbooks.

**References**


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Engineering as a Caring and Empathetic Discipline: Conceptualizations and Comparisons

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Abstract: Community concerns and habits of mind like systems thinking, collaboration and communication are core attributes of engineers. Two traits, which underscore many of these ideal attributes, are empathy and care. While engineering as a field is just recognizing these attributes, other disciplines have mastered the integration of empathy and care into their regular curricula. The purpose of this study was to research how empathy and care are conceptualized in engineering and other disciplines and how it is incorporated into the curriculum. Results demonstrate variance and provide insights for practice.

Introduction

A study of public perceptions of engineering revealed that “engineers are not perceived to be as engaged with societal and community concerns or to play as great a role in saving lives” (NAE, 2008, p17-18) as scientists. In psychological terms, engineering is often perceived as object-oriented rather than people-oriented (Malcom, 2008). Many students who are interested in careers that are related to helping people may not pursue an engineering-related degree in the future or transfer to a program that is thought to be more oriented towards working for a social good (Borrego, Padilla, Guili, Ohland, & Anderson, 2005).

Recognizing the changing roles and functions of engineers, organizations such as the US National Academy of Engineering have emphasized the need to promote engineering “habits of mind”, which include systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations (NAE, 2009). Two traits that underscore many of the attributes ideal for the “engineer of 2020” are empathy and caring (defined in next section). Being able to understand the experience of others – a widely accepted definition of empathy (see Berger, 1987) and helping others to grow in their unique ways and pace (definition of care: see Mayeroff, 1965; 1971) are vital to understanding problems, designing solutions, effective communication, multicultural competency, and relationship building. While engineering as a field is just recognizing these attributes, other disciplines and fields have mastered the integration of teaching of empathy and caring into their regular curricula. Engineering as a field, and engineering
education in particular, can learn from disciplines that incorporate empathy and caring as part of long standing core values and learning outcomes. In this study, we explored the following research question:

How are empathy/care conceptualized, integrated into standards and taught in disciplines with a longstanding tradition of being considered “empathetic” and “caring” compared to engineering disciplines?

An short summary and introduction to empathy and care

Empathy and care are conceptualized and taught in many disciplines.

Empathy/care have been conceptualized and taught in a multitude of ways in the nursing, medicine, counselling and education fields. For example, Kohut (1984) defines empathy as “the capacity to think and feel oneself into the inner life of another person” (p10). Berger (1987) describes empathy as “The capacity to know emotionally what another is experiencing from within the frame of reference of that other person, the capacity to sample the feelings of another or to put oneself in another’s shoes” (p2). Similarly caring is defined in multiple ways. Hawk & Lyons (2008) define that “an ethic of care is a reflective and action-oriented process about learning of the other and demonstrating relationship behavior that seeks to recognize, value, trust, and develop the other” (p.320).

Empathy and care are integrated into professional standards

Our review of professional organizations and their standards shows that care and empathy have been integrated into a variety of professional standards. For example, American Physical Therapy Association considered caring as one of the core values of professionalism in physical therapy and they defined caring as the concern, empathy and consideration for the needs and values of others.

Although empathy and care are incorporated into standards in many disciplines, it is rarely the case in engineering fields: In The Vision for Civil Engineering in 2025 by American Society for Civil Engineers, it is expected that the civil engineer should know how to: “Lead by formulating and articulating environmental, infrastructure, and other improvements and build consensus by practicing inclusiveness, empathy, compassion, persuasiveness, patience, and critical thinking.” While we didn't find empathy and care explicitly appear in other engineering standards, it would be premature to draw the conclusion that other engineering organizations do not include features or attributes of care and empathy in their standards.

The relationship between empathy and care

There is no consensus in literature regarding the relationship between empathy and caring. Some authors argue that empathy leads to caring (Batson, 1990), others assert that caring leads to empathy (Määttä, 2006). Researchers argue that caring is a component of empathy (Fernández-Olano, Montoya-Fernández & Salinas-Sánchez, 2008), while there are also ones who think empathy is a component of caring (White, 1997). Given the debate on the relationship between empathy and care, it can be argued, the two concepts are
closely related with each other. In broader terms, both empathy and caring are consistently conceptualized as a characteristic of the individual or a process rather than the product (Mayeroff, 1965, 1971; Duan & Hill, 1996).

Although empathy and care are widely incorporated in social science research, they are less conceptualized in engineering. Our literature search results in less than 40 papers explicitly mentioning empathy and caring in engineering.

**Theoretical Foundation**

Theory of mind (ToM) and simulation theory have been used to conceptualize empathy. Theory of mind has been defined as “the ability of individuals to attribute mental states to themselves and others in order to explain and predict behavior” (p. 119; Sutton, Smith, & Swettenham, 1999). While theory of mind (ToM) focuses on the learning and experience of an individual in discerning the mental or emotional state of others, simulationists believe that ToM is based on an individual’s intuitive or innate sense of what another person is thinking or feeling (Keysers & Gazzola, 2007).

Research conducted in cognitive science has found that different areas of the brain are active depending on whether a person is reflecting upon the state of others (ToM) or whether a person is intuitively experiencing first-hand the emotions or states of others (simulation) (Keysers & Gazzola, 2007) arguing even further that empathy may be a non-conscious response (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003). Keysers and Gazzola (2007), however, demonstrate that both are necessary to more fully describe and explain empathy.

**Methodology**

**Literature Review.** A systematic literature review (Center for Reviews and Dissemination, 2001) was conducted to search and synthesize literature on empathy and care. The search process consisted of a manual search of electronic databases accessible through our University Library System and a manual search of the Internet using Google and Google Scholar. The search process for literature about “empathy” and “caring” consisted of parallel processes done separately, as the research team treated them as two constructs. Two different researchers conducted the parallel search processes closely coordinating their methods. Databases included education, social science, engineering and databases in fields determined as traditionally fields of high presence of empathy and care.

**Inclusion Criteria:** Articles were selected based on the following criteria. Articles must include an original conceptualization of “empathy/care,” a conceptualization of “empathy/care” generated by study participants, a method of teaching “empathy/care,” or professional standards including “empathy/care.” Articles must also be written in the English language, be qualitative or quantitative research studies or review articles, be published in peer-reviewed journals, and be published after 1980. Heavily cited articles published earlier than 1980, with original conceptualizations of “empathy/care,” were...
also included. Our inclusion is focused on the use of the terms “empathy/care” not because there is no evidence of attributes of empathy and care in other engineering literature. On the contrary, the evidence for implicit use of attributes of care/empathy is rather strong in the literature on values and ethics (Love, 1998) and the literature on user-centered design (Abras, Maloney- Krichmar, Preece, 2004). We chose deliberately to restrict our search to the actual terms to emphasize the need to establish systematic discourse, which requires clearly articulated and defined terminology.

Data Collection: The following pieces of data were collected from each article, as available: full citation, discipline, and summary of the conceptualization(s) of “empathy/care”, method(s) of teaching “empathy/care”, or professional standard(s) including “empathy/care.” Examples were not limited to, defining attributes, characteristics, and requisites of “empathy/care,” heavily cited (influential) authors and articles conceptualizing “empathy/care,” and verbatim definitions of “empathy/care.”

Analysis: Literature was analysed using constant comparative method (Corbin & Strauss, 1998) and discourse analysis following Gee’s framework (2010).

Results

Frequency of conceptualizations in engineering literature

The comprehensive literature review resulted in only twenty-two engineering papers which embedded the concept of empathy, compared to thousands of empathy-related papers published in other fields (Table 1). Nearly matching results exist for the term care (see Table 2).

Table 1. Engineering Articles that Reflect Empathy (selected)

<table>
<thead>
<tr>
<th>Engineering Education</th>
</tr>
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</table>


**Engineering Management**


**Engineering Ethics**


**Engineering Professional Development**


<table>
<thead>
<tr>
<th>Table 2. Engineering Articles that Reflect Caring (selected)</th>
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<tbody>
<tr>
<td><strong>Engineering Education</strong></td>
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<tr>
<td><strong>Engineering Design</strong></td>
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Interpretive Results

The interpretive results are structured to allow a separate view on empathy and care.

**Observed Differences Between Conceptualizations of Empathy in Engineering Fields and Conceptualizations of Empathy in Fields Outside of Engineering**

Comparing the conceptualizations of empathy in engineering literature and those found in literature outside of engineering points to interesting differences in the language authors tend to use when describing empathy:

a) **Direct vs. indirect interaction with users**

Conceptualizations of empathy in the literature of more traditional helping fields tend to focus more on how empathy may be demonstrated while directly interacting with and building relationships or connections with clients or populations being helped, primarily through the use of empathic communication. Authors conceptualizing empathy in the traditional helping professions tend to use terms such as caring, helping, supporting, and

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**Computer Engineering**


**Engineering Ethics**


serving in conjunction with empathy significantly more than their counterparts in engineering fields.

Engineering literature tends to endorse engineers’ use of empathy when designing products for the user or customer and/or solving problems for the user, without the engineer necessarily having direct contact with the user. For example, Vallero & Vesilind (2006) believe that empathy is part of the design process and it can appear at each step of the engineering design and build process. In order to be empathetic, engineers should consider the needs of the client and the impact of their design, etc. Fleischmann (2004) considers empathy as “the ability to place yourself in someone else’s place and to walk with them as you attempt to understand the problem that you will attempt to solve”. He states that empathy is closely related to engineering professionalism. It reflects quality of the heart and is one of the virtues engineering students should know.

**b) Empathy towards co-workers and colleagues**

Engineering literature also tends to endorse engineers’ use of empathy when interacting with people in their workplace. Masi (1995) argues that engineers need empathy with team members. He defines empathy as “knowledge of when to speak out and when to let someone else talk and the ability to defend ideas without generating confrontations-just to do their jobs”. Shainis (1988) views empathy as the ability to look at things from another person's point of view and insists that it is important for engineering manager or project engineer to be empathetic with people they encounter in workplace. Based on these findings, engineering educators are encouraged to help their students develop empathy skills primarily for the purpose of establishing collaborative partnerships with colleagues in the workplace or for improving team management and leadership skills. The role of empathy to form a collaborative relationship with the person or persons using the technology they develop is not as strongly conceptualized (Riemer, 2003).

**Arguments for Incorporating Empathy into Engineering Curricula.**

While many of the arguments for incorporating “process skills” like empathy into engineering curricula follow in the footsteps of ABET’s requirements, the call for incorporating empathy into engineering programs is not a new one. For example, our literature search produced several – decades old - documents that urge engineering educators to base their curricula on, for example, the “needs of mankind today” in order to develop empathic, humanized engineering professionals (Kopplin, 1969).

Today, engineering programs are being challenged to align their curricula with current ABET requirements and the changing demands of the twenty-first century global marketplace, which expand the role and the necessary competency base of the engineer (Berndt & Paterson, 2009; Kumar & Hsiao, 2007; Riemer, 2003). A growing sector of engineering programs is also offering courses and degrees in engineering and sustainable development, humanitarian engineering, community service and other initiatives aimed at helping communities “in need” (Schneider, Lucena, & Leydens, 2009). Many of the papers challenge the exclusive focus on technical skill development and ask to incorporate the learning and practicing of “process skills” like empathy into engineering curricula (Hey,
Several authors contend that traditional engineering programs do not adequately prepare students with the range of skills needed to function in the modern multicultural workplace, including the ability to empathize with others when working in teams or when in a leadership or management position (Riemer, 2003) and abstract problem-solving and interpersonal complexities (Leyden & Lucena, 2009; Masi, 1995; Wirth, 2010). In addition, modern engineering managers must not only understand the perspective of his or her supervisees and team members, but also take into account the larger perspective of the society in which he or she is working (Shainis, 1988; Vallero, 2008). Most of these skills, including empathy, are typically learned "the hard way" when engineering students enter the workplace (Kumar & Hsiao, 2007; Leyden & Lucena, 2009).

Other engineering papers contend that engineers need empathy skills, which include listening, observing, and understanding skills, in order to understand the needs and expectations of the customers or users of the products they develop (Hey, 2007; Steiner, 1998; Vallero & Vesilind, 2006; Wright, 2001). Customer “need finding” skills, similar to the empathy skills needed for working with co-workers mentioned above, require engineers to go beyond thinking in a linear manner to thinking more abstractly than typically required or taught in an engineering setting (Hey, 2007). The authors argue that if the needs of the customer and the larger population are not considered in the design and production phases, “there is a likelihood that project will be of little value or will have ancillary harm. To be an effective and ‘good’ engineer requires that we be able to put ourselves in the place of those who have given us their trust” (Vallero & Vesilind, 2006). Traditional engineering textbooks and classrooms do not prepare students for the difficult task of identifying customer and societal needs that are not always clearly stated or easily conceptualized (Hey, 2007). In addition, Riemer (2003) demonstrates that without empathy skills, students’ performance in their engineering program may suffer and that they may be more likely to drop out of the program or demonstrate poorer quality performance in the workplace.

It is interesting to note our search produced only one engineering professional organization that explicitly includes empathy in its vision statements or professional standards. The American Society for Civil Engineers’ Vision for Civil Engineering in 2025 states, "The civil engineer is skilful. He or she knows how to: lead by formulating and articulating environmental, infrastructure, and other improvements and build consensus by practicing inclusiveness, empathy, compassion, persuasiveness, patience, and critical thinking."

**Observed Differences Between Conceptualizations of Care/Caring in Engineering Fields and Conceptualizations of Care/Caring in Fields Outside of Engineering**

In traditional fields, caring is often conceptualized as an interpersonal relationship. It is related with giving and receiving help. The one who cares has to be able to apprehend other’s situation and address the needs. In some of these traditional fields, such as nursing,
caring is regarded as the core or essential value of the profession. Besides, the ethics of care is often considered as a feminist ethics.

In engineering field, caring seems to be understood in various ways.

**a) Care is delivered by designing products that satisfies users’ need**

In traditional fields, caring is often depicted as an interpersonal relationship between the one caring and the one cared for. Helping professions show their care for clients by directly interacting with clients. The words like “support” “respect” “encourage” “trust” are often used to describe this interactive process, which suggests that people tend to establish a strong emotional bond through the caring process. In contrast, in engineering field, care is given in an indirect way. Literature indicates that engineers first analyse users’ need (Ma, 2011) and deliver their care by designing product that meets users’ demands. E.g. "The design ought to show due care for persons. It should take into account its effects on individuals – physically, socially, and psychologically. Technological solutions should address a real need, [...] while keeping the individual in mind. This should include an attitude on the part of engineers that recognizes that technology does not exist for its own sake, but to better the lives of other" (Ermer & Vanderleeest, 2002, p.6). "Therefore, matching the functional, emotional and environmental aspects for the products is considered during designing rehabilitation training bed. So the products can give more attentive care and human love, and they also satisfy the users in material and spiritual aspects" (Ma, 2011). "The system must be able to be installed at the point of care in a way that delivers the experience under the patient’s control, without compromising the function or safety of the clinical environment" (Hegarty, Roch, McCabe & McCann, 2009).

**b) Care as a guiding principle for engineering design and problem solving**

Pantazidou & Nair (1999) argued that the basic steps of engineering design actually embodied the ethic of care and they attempted to draw analogies between the ethics of care, the design method and the problem solving method, by mapping the components of the ethic of care to the design process and problem solving process. Pantazidou & Nair (1999) believed that both care and engineering emerged as a response to a need and was oriented towards practice.

**c) Care/Caring as an important component in environmental education**

Learning the concept of care/caring is particularly emphasized in environmental engineering education. Hyde & Karney (2001) introduced an ethic of care in environmental education, where caring had been comprehended in the phrase “environmental sensitivity,” which could be further explained as “a predisposition to take an interest in learning about the environment, feeling concern for it, and acting to conserve it, on the basis of formative experiences”. Zimmerman, Vanasupa, Mihelcic & Zhang (2008) described the new book they created to teach environmental engineering. The book incorporated the concept of “Caring” as “the concept of sustainability where economic, societal, and environmental systems are integrated” and Zimmerman et al (2008) wanted to “help students adopt the systems perspective of engineering solutions and develop feelings for the environment and society”. Although teaching care/caring is encouraged to
incorporate into engineering education, we didn’t find much literature suggesting what actions to take in order to demonstrate care. Therefore, it is still not clear what care/caring looks like in practice.

d) Care as professional duties

Kardon (2005) summarized “standard of care” in engineering into four duties: 1) the duty to have that degree of learning and skill ordinarily possessed by reputable professionals; 2) the duty to use the care and skill ordinarily used in like cases by reputable members of his or her profession practicing in the same or similar locality under similar circumstances; 3) the duty to use reasonable diligence and his or her best judgment in the exercise of professional skills and in the application of learning; 4) the duty to make effort to accomplish the purpose for which he/she is employed. Kardon (2005) argued that once an engineer had failed to meet the standard of care, he/she was professionally negligent.

e) Caring as a feminine approach in engineering

Starobin, Jackson, Darrow & Laanan (2010) interviewed nine community college STEM faculty, administrators, and program coordinators who participated in a project, aiming at increasing the participation of women and underrepresented populations in STEM. It was found that engineering was characterized as a caring and helping profession when advising female students.

“When the ladies or women come to my office and show the interest of sometime concern because this is a man field they kind of worry or are concern and we talk the women science usually is caring, nurture so we talk about what the engineering can help people or can in the field of helping.”

“We’ll talk to the students or potential students about what engineers do but we re-characterize science and engineering somewhat into helping how, how engineers help people how engineers make a difference in the world, both on an individual level and a general societal level too. This seems to ring a very strong chord with women in particular. So that’s the one of the big messages that we give them and so we try to provide examples of how engineers help people and what a career might look like and also what an educational path would look like through those…”

This finding is similar to what was found in other fields, where caring was reported as a feminine approach to ethics. Therefore, connecting engineering with caring might attract more female engineering students (Haws, 2001). The result from Christy, Lima & Cauble (1999)’s research actually supports this argument. In their study, 32 female professors in Biological/Agricultural (and related) Engineering (BAE) were asked to give their opinions in essay format on why BAE was attracting and retaining more women compared to other engineering disciplines. Some responses were:

“Areas where there is a higher percentage of women engineers usually are related to somewhat of a nurturing, healing, or caring type technology such as environmental, biomedical or food sciences.”
“Girls become familiar with chemistry biology and the environment in high school. I believe this helps them make a connection with biological, chemical and environmental engineering. This is not the case with physics and ME, CE and EE.”

**Arguments for Incorporating Care/Caring into Engineering Curricula**

Several papers we found emphasized the benefit and need to incorporate teaching care/caring into engineering education. For example, Pantazidou & Nair (1999) argued, that engineers need to understand engineering activity and its short- and long-term impacts, together with the complex sequence. They proposed that weaving ethics throughout engineering education would enable students to become aware of these non-technical dimensions of engineering. Haws (2001) also believed that a formal training in ethics would help engineers consider the ethical perspectives of virtue, rights, justice and care, as well as utility, thus enabled engineers to evaluate options and impacts beyond the narrow realm of engineering.

However, how to effectively incorporate care/caring into engineering curricula still remains a challenge for engineering educators. For example, Zhang, Vanasupa, Mihelcic & Zimmerman (2010) identified that one of the difficulties for teaching sustainability in engineering was the lack of effective learning materials that added learning outcomes related to caring and the human dimension to typical learning outcomes. Hyde & Karney (2001) pointed out explicitly that caring was a missing component of engineering curriculum. One paper we found talked about the idea of treating caring as one of the design norms and forcing students to design to such norms. Therefore, students learn to evaluate whether their design products met the caring criteria (Ermer & Vanderleest, 2002).

**Conclusion**

Our review and comparison of literature on care and empathy in engineering suggests engineers can deliver both care and empathy when designing products for the user or customer and/or solving problems for the user. However, there is still no agreement on the meaning of care and empathy in engineering, especially when we take into consideration the many different ways care is understood in engineering. Our findings also indicate that researchers and practitioners already realize the benefit and need to integrate the development of care and empathy into engineering education. Many authors advocate incorporating more soft or process skills into engineering curricula and into the toolkit of engineering professionals. Findings from this study illuminate qualitative differences between engineering and other fields on how empathy and care are defined, which might be able to shed light on the notion of how empathy and care could be incorporated into engineering curricula. Further research on practice of engineering and classroom interventions are necessary.

**References** (see also the literature in Table 1 and Table 2 of the results as they contain full references)


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Topic: Transition 2 - Chair: Johannes Strobel

Development of learning environments to increase the understanding and interest in engineering and technology amongst Australian primary school students

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Abstract: The paper reports on the results of an action research study, aimed at developing interest and understanding among primary school students in the fields of engineering and technology as potential career choices in order to redress the inadequate supply of trained professionals in the fields of Engineering and Technology. Data was collected by administering a modified version of a pre-validated pictorial questionnaire ‘Engineering is Elementary’ (EIE) twice to 340 students from 15 primary classrooms in years 4, 5 and 6 in Perth, Australia in a three phase study. In the first phase students’ existing understanding about ‘What Engineers Do?’ and ‘What is Technology?’ were explored. In the second phase a lecture explaining the relationship between Science, Technology and Engineering was delivered in each of the participating classes followed by three engineering related student activities. In the third phase the EIE was readministered and significant differences in student understanding were identified in recognition of the items in the EIE suggesting that an intervention programme could play key role in creating students interest in engineering and Technology.
Introduction

Despite massive advances in science, few citizens worldwide are technologically literate, largely because technology and engineering are seldom taught in schools (Lachapelle & Cunningham, 2007). Just as it is important to begin science instruction in primary school by building on children’s curiosity about the natural world, it is also important to begin engineering instruction in primary school by building on children’s natural inclination to design, build and take things apart (Cunningham & Hester, 2007). At the heart of engineering is an understanding of the engineering design process – a highly flexible method of solving problems. It is essential that young people's interest in science, technology and engineering is stimulated and maintained throughout their schooling so that students continue with studies in these fields at the university level in order to address the skills shortage (MCEETYA, 2006). A community with an understanding of the nature of science and scientific inquiry will be better equipped to participate in an increasingly scientific and technological world (Williams, 2001). Opening young minds to the wonders of the natural world, stimulating curiosity and creative thinking, and starting that journey towards scientific and technological literacy, requires a strong and effective primary school engineering programme.

Science through engineering can be seen in every aspect of the built environment and it is essential to Australia’s prosperity, lifestyle and global competitiveness. As Australia moves into the knowledge-based economy, it is vital for Australia’s future development that the number of engineering graduates increases. To increase the number of engineers, children must develop an interest in science, engineering and technology throughout their school lives. Accordingly, cultural and curriculum changes within the schooling system need to occur. In Australia while the numbers of students completing Year 12 have increased, the proportion of students interested in studying chemistry, physics and advanced mathematics has declined, and initiatives to address this decline need to be implemented as a matter of urgency (Wogan, 2011).

Research Questions

The overarching aim of this project was to develop interest and understanding through improved learning environments among primary school students in engineering and technology (E & T) as potential career choices in order to redress the problem of insufficient numbers in the pool of locally-trained professionals in these fields. Further, the project aimed at developing the engineering and technology literacy of primary school students and teachers. The objectives of this study are:

- To investigate what activities primary school students classify as being E & T.
- To develop and validate an instrument to assess the primary school students’ learning environment and their understanding and interest in E & T.
- To investigate year-level, gender and cultural differences in primary students’ classroom learning environment perceptions and understanding and interest in E & T.
➢ To assess the effectiveness of the implemented E & T lessons in terms of the quality of the classroom learning environment and student understanding and interest in E & T.

**Theoretical Framework(s)**

**Learning Environment Research**

The study drew upon and contributed to the burgeoning field of learning environments (Fraser, 2007). Contemporary research on school environments partly owes its inspiration to Lewin’s (1936) seminal work in non-educational settings, which recognised that both the environment and its interaction with the characteristics of the individual are potent determinants of human behaviour. Since then, the notion of person-environment fit has been elucidated in education by Stern (1970), and Walberg (1981) has proposed a model of educational productivity in which the educational environment is one of nine determinants of student learning. Over the last four decades, learning environment research has become a firmly established form of research on teaching and learning (Fisher & Khine, 2006).

A hallmark of the field of learning environments is the existence of a variety of economical, robust and extensively validated questionnaires that measure different psychosocial dimensions of the classroom. These instruments are used to investigate the learning environment more closely from the perspective of the students who make up a classroom rather than from the perspective of trained observers or teachers.

One of the most promising applications of classroom environment assessments is their use as process criteria of effectiveness in evaluating educational programmes. For example, when Martin-Dunlop and Fraser (2007) used learning environment criteria in evaluating an innovative science course for prospective American primary teachers, students reported very large gains in classroom open-endedness and material environment between the beginning and end of the course. Similarly, when Nix, Fraser and Ledbetter (2005) evaluated the impact of an innovative teacher development programme based on the Integrated Science Learning Environment (ISLE) model in school classrooms, students whose science teachers had attended the ISLE program perceived more positive learning environments in their classrooms relative to the classrooms of other science and non-science teachers in the same schools. In the proposed study, we also will use learning environment criteria in evaluating the effectiveness of the implemented engineering programme.

**Grade-level and Gender Differences**

Previous studies have revealed differences in students’ learning environment perceptions, understanding and interest according to grade level, gender and cultural background (Aschbacher, Li, & Roth, 2010; Fraser, Giddings, & McRobbie, 1995; Kim, Fisher, & Fraser, 1999, 2000; Koul & Fisher, 2005; Koul, 2010). In our continuing study, we will investigate differences in students’ perceptions of classroom environment and understanding and interest in E & T according to grade level (years 4, 5 and 6), gender and cultural
background (defined in terms of the students’ or parents’ place of birth). In Australia gender differences are of special interest in our study because engineering is considered to be a male-dominated area and, despite the efforts of government and educationists, currently less than 7% of working engineers are females (Engineers Australia, 2008) and female undergraduate enrolments in engineering is averaging between 15-19% across most disciplines apart from Chemical Engineering where it is between 25 to 30%.

**Methodology**

The initial study involved 340 students from 15 primary classrooms in five schools in years 4, 5 and 6 in Perth, Western Australia. A survey instrument by Lachapelle and Cunningham (2007) was modified and implemented to assess these students’ understanding and interest in E & T. As only some of the photos were replaced, without changing the meaning of the concept illustrated, the validity of this instrument has not been changed, having a reliability of 0.97 for Engineering section and 0.93 for the Technology section. After the survey a lesson defining engineering and the importance of Science, Engineering and Technology was delivered to these classes by the first author who is an engineer by training. In addition at least one engineering topic (two to three lessons), chosen by the class teachers was taught in these classes. Researchers used lesson plans from ‘Tryengineering’ (www.tryengineering.org) as a guideline and modified them to fit local needs. Teachers were given the lesson plans, materials and any other support they needed for these lessons. These lessons were observed by at least one researcher. A post-test survey was administered to these students to find any changes in understanding and interest in E & T. Table 1 represents the demographic information about the participating students in the study.

**Table 1. Demographic information about the sample**

<table>
<thead>
<tr>
<th>School</th>
<th>Student No</th>
<th>Percentage of cohort (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>67</td>
<td>19.7</td>
</tr>
<tr>
<td>2</td>
<td>77</td>
<td>22.6</td>
</tr>
<tr>
<td>3</td>
<td>69</td>
<td>20.3</td>
</tr>
<tr>
<td>4</td>
<td>54</td>
<td>15.9</td>
</tr>
<tr>
<td>5</td>
<td>73</td>
<td>21.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Student No</th>
<th>Percentage of cohort (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>126</td>
<td>37.1</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>35.3</td>
</tr>
<tr>
<td>6</td>
<td>94</td>
<td>27.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parent engineer</th>
<th>Student No</th>
<th>Percentage of cohort (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>33</td>
<td>9.7</td>
</tr>
<tr>
<td>No</td>
<td>307</td>
<td>90.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gender</th>
<th>Student No</th>
<th>Percentage of cohort (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys</td>
<td>147</td>
<td>43.2</td>
</tr>
<tr>
<td>Girls</td>
<td>193</td>
<td>56.8</td>
</tr>
</tbody>
</table>

**Findings**

**Perception of Engineering and Technology**

The survey probed children’s perception of engineering and technology, asking them ‘What does an engineer do?’ and ‘What is technology?’, to draw examples of what an engineer does and what is technology, and to describe their pictures in words. The results indicated that students generally had a poor idea about the type of work engineers do...
while more than 60% students had stronger understanding about technology. Very few students wanted to take up engineering related careers, however, there was an increase in student career aspirations as well as understanding of engineering and technology in the post-test results. Details of the results can be seen in Table 2.

In order to more systematically probe student’s perceptions of E & T, the questionnaire included both captioned images of working people from which the students had to choose those that showed what an engineer would be expected to do at work, and other captioned images of items that may or may not represent technology while asking students, “What is technology?” In both tests the students showed a significant shift towards selection of correct responses between the pre-test and post-test results (please see Tables 3 and 4).

As part of our evaluation of the E & T teaching, we examined the pre-test/post-test changes in students’ perceptions that occurred during the instruction. Each wrong answer was marked as zero and right as one. The magnitude of each pre-test/post-test difference is described in Tables 3 and 4, in terms of effect size (i.e. the number of standard deviations), whereas a t-test for paired samples was used to determine the statistical significance of this difference.

<table>
<thead>
<tr>
<th>Table 2 Student work aspirations and understanding of Engineering and Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Work aspiration (What would you like to be when you grow up?)</strong></td>
</tr>
<tr>
<td>Student No</td>
</tr>
<tr>
<td>Engineering</td>
</tr>
<tr>
<td>Non engineering</td>
</tr>
<tr>
<td>No response</td>
</tr>
<tr>
<td><strong>Engineering brainstorm (What does an engineer do?)</strong></td>
</tr>
<tr>
<td>No idea</td>
</tr>
<tr>
<td>Poor idea</td>
</tr>
<tr>
<td>Moderate idea</td>
</tr>
<tr>
<td>Sound idea</td>
</tr>
<tr>
<td><strong>Technology brainstorm (What is technology?)</strong></td>
</tr>
<tr>
<td>No idea</td>
</tr>
<tr>
<td>Poor idea</td>
</tr>
<tr>
<td>Moderate idea</td>
</tr>
<tr>
<td>Sound idea</td>
</tr>
</tbody>
</table>

Effect Size, in terms of the differences in means divided by the pooled standard deviation ranged between 0.08 to 1.32 standard deviations for the engineering test and 0.06 to 0.98 standard deviations for the technology test. The effect sizes for the engineering questions were larger for most scales.

The engineering test recorded statistically significant changes in all items pre-test/post-test differences except for the item of ‘work as electrician’ and ‘drive machine’. Similarly only three items demonstrated insignificant changes in pre-test/post-test differences in the technology test.
Conclusions

The results of this pilot study have demonstrated that at the time of the pre-test students had a fair understanding of what technology meant and generally very poor understanding of what engineers do. Students and teachers enjoyed the E & T lessons and statistically significant differences were recorded in students understanding in the post-test. Further work is continuing to incorporate research, evaluation and assessment into all aspects of curriculum design and testing from its inception. Our research questions, assessment instruments and curriculum continue to evolve.

Table 3: Item Mean and Standard Deviation for Pre-Post tests in Students’ Perceptions on the items in the Engineering Questionnaire

<table>
<thead>
<tr>
<th>Item</th>
<th>Item mean</th>
<th>Item SD</th>
<th>Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design circuits</td>
<td>0.69</td>
<td>0.87</td>
<td>0.46</td>
</tr>
<tr>
<td>Make better food</td>
<td>0.02</td>
<td>0.09</td>
<td>0.13</td>
</tr>
<tr>
<td>Design machines</td>
<td>0.75</td>
<td>0.96</td>
<td>0.43</td>
</tr>
<tr>
<td>Better farming</td>
<td>0.15</td>
<td>0.37</td>
<td>0.35</td>
</tr>
<tr>
<td>Design better phones</td>
<td>0.46</td>
<td>0.82</td>
<td>0.49</td>
</tr>
<tr>
<td>Design MRI</td>
<td>0.44</td>
<td>0.78</td>
<td>0.49</td>
</tr>
<tr>
<td>Design tablets</td>
<td>0.04</td>
<td>0.54</td>
<td>0.21</td>
</tr>
<tr>
<td>Protect coastline</td>
<td>0.13</td>
<td>0.32</td>
<td>0.34</td>
</tr>
<tr>
<td>Work as a team</td>
<td>0.57</td>
<td>0.83</td>
<td>0.49</td>
</tr>
<tr>
<td>Make smaller recorders</td>
<td>0.31</td>
<td>0.67</td>
<td>0.46</td>
</tr>
<tr>
<td>Design bridges</td>
<td>0.56</td>
<td>0.90</td>
<td>0.49</td>
</tr>
<tr>
<td>Design space shutters</td>
<td>0.49</td>
<td>0.79</td>
<td>0.50</td>
</tr>
<tr>
<td>Work as electrician</td>
<td>0.39</td>
<td>0.35</td>
<td>0.49</td>
</tr>
<tr>
<td>Build houses</td>
<td>0.59</td>
<td>0.48</td>
<td>0.49</td>
</tr>
<tr>
<td>Drive machines</td>
<td>0.69</td>
<td>0.73</td>
<td>0.46</td>
</tr>
<tr>
<td>Repair machines</td>
<td>0.20</td>
<td>0.27</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Table 4: Item Mean and Standard Deviation for Pre-Post test in Students’ Perceptions on the items in the Technology Questionnaire

<table>
<thead>
<tr>
<th>Item</th>
<th>Item mean</th>
<th>Item SD</th>
<th>Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV</td>
<td>0.96</td>
<td>0.98</td>
<td>0.19</td>
</tr>
<tr>
<td>Train</td>
<td>0.76</td>
<td>0.89</td>
<td>0.43</td>
</tr>
<tr>
<td>Running shoes</td>
<td>0.09</td>
<td>0.49</td>
<td>0.29</td>
</tr>
<tr>
<td>Telephone</td>
<td>0.94</td>
<td>0.97</td>
<td>0.24</td>
</tr>
<tr>
<td>Tea cup</td>
<td>0.05</td>
<td>0.12</td>
<td>0.21</td>
</tr>
<tr>
<td>Manufacturing plant</td>
<td>0.62</td>
<td>0.78</td>
<td>0.49</td>
</tr>
<tr>
<td>Refinery</td>
<td>0.54</td>
<td>0.75</td>
<td>0.49</td>
</tr>
<tr>
<td>Computer</td>
<td>0.97</td>
<td>0.98</td>
<td>0.16</td>
</tr>
<tr>
<td>Bicycle</td>
<td>0.14</td>
<td>0.34</td>
<td>0.35</td>
</tr>
<tr>
<td>Bridge</td>
<td>0.13</td>
<td>0.42</td>
<td>0.34</td>
</tr>
<tr>
<td>Genetics (artificial arm)</td>
<td>0.31</td>
<td>0.47</td>
<td>0.46</td>
</tr>
<tr>
<td>Spaceship</td>
<td>0.83</td>
<td>0.90</td>
<td>0.37</td>
</tr>
<tr>
<td>Tree</td>
<td>0.98</td>
<td>0.96</td>
<td>0.13</td>
</tr>
<tr>
<td>Bird</td>
<td>0.99</td>
<td>0.97</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Recommendations and future research plans

There will be a continuing effort to run similar projects for primary and secondary school students. This effort needs to be strengthened by professional development of teachers and a unit on engineering education added into teacher education programmes. Sustainable courseware can only exist with teacher support.

References


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Starting young: Learning outcomes of a developmentally appropriate PreK engineering curriculum

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Abstract: Engineering education for the pre-college years is a developing discipline. To date there are no curricula available for the preschool level. Focus of this study is on the development of an early engineering curriculum that will complement the traditional emphasis on developing basic literacy, numeracy, and science along with social, emotional, and motor skills, while retaining high fidelity of the early engineering content addressed. Current work presents a qualitative case study examining the developmental appropriateness of the curriculum and reports on effect on children's learning. Setting is a university campus-based child care program in the Midwestern U.S. Participants is 11 children, their parents and the teacher. Data include researcher's field-notes; teacher's notes, weekly journal, and exit interview; records of children's work; and parents' questionnaires and letters. Children's learning is analysed based on the categories of knowledge, skills, dispositions, and feelings. Findings support the developmental appropriateness of the early engineering curriculum, along with the feasibility and the necessity of the implementation.

Introduction

The most recent calls for reform in engineering education began a decade ago and have been acknowledged and supported by many engineering professional societies, organizations, and scholars. A brief review of the history of the calls reveals that it began with recognition of changes in global demand and a wish to keep the US competitive (National Academy of Engineering, 2004; Haghighi, 2005; Augustin, 2007). Until recently, most of the efforts concentrated on reforming engineering education at the college level. The fact that engineering is known as a formal post secondary discipline limited the conversation to the question of how to best educate engineers and what research must be carried out to inform that question. However, it has become apparent that engineering education is more than just the education of engineers and that the discipline must also be concerned with what happens before and after formal college level engineering education (Brophy and Evangelou, 2007; Bagiati and Evangelou, 2009; ).

Introducing engineering into pre-college education appears so far to be following a 12-K approach. Effort is mainly centred on high school and middle school students, and some programs have been developed for the upper elementary grades. However, in early
education, resources are still very limited. Scattered activities or small scale engineering lesson plans can be found for a teacher to use in class, mainly presented without an assessment tool (Bagiati & Evangelou, 2009); but no outreach programs, standards, or complete PreK-3 engineering curriculum setting a clear teaching philosophy, learning goals, and assessment tools exist yet (Bagiati, Yoon, Evangelou, & Ngambeki, 2010).

In addition to the lack of valid engineering curricula for the early years, obstacles appear to be teacher uneasiness with engineering content, terminology, and procedures. Limited exposure to such content, in addition to its reputation as a difficult discipline that requires rigorous specialization, makes most teachers feel inadequately prepared to deal with it in the curriculum (Bagiati, Yoon, Evangelou, & Ngambeki, 2010).

Despite the nascent state of the field of early engineering education, recent research indicates that during free play or interaction with familiar or unfamiliar artefacts, children demonstrate curiosity, interest, motivation, and the capacity to draw inferences (Evangelou, Dobbs-Oats, Bagiati, Liang, & Choi, 2010). Furthermore children demonstrate the ability to perform and complete age appropriate simple engineering and design related tasks, even if they have very limited exposure to engineering content or terminology (Johnsey, 1993; Fleer, 2000). These behaviours, it is suggested, can be perceived as precursors to engineering thinking (Brophy & Evangelou, 2007).

**Research Question**

The current study investigates a semester-long, age-appropriate engineering design-based curriculum, and will identify whether this curriculum is a way of achieving higher knowledge integration of STEM in a preschool classroom. For the remainder of the paper the term “STEM” will refer to the integration of science, technology, engineering, and mathematics, and the early engineering curriculum (EEC) will refer to the curriculum developed in current study under the assumption that this is addressing the STEM integration, with primary emphasis on the engineering component. The study employs a view of engineering as a disciplinary domain that uses math, science, and technology as tools, but which also requires synthetic ability, design, problem solving, organization, and construction skills, and incorporates various types of communication as well. From this viewpoint, engineering is thus more than the sum of the STEM parts; it is indeed the integrative nature of engineering that makes it appealing in an educational context (Brophy and Evangelou, 2007).

The following research question guides this study:

*What type of children’s STEM learning might occur as children participate in a developmentally appropriate STEM curriculum?*

**Theoretical and methodological framework**

Preschool curriculum can be seen as a form of intervention specifically aimed at the achievement of developmental goals through the delivery of specific educational content. This function of the curriculum is used to incorporate engineering content and investigate
its effects on children’s learning as they participate in class and the teacher’s experience as she is changing her teaching reality to implement the new curriculum.

Learning in this study is defined by Katz (1999) as a synthesis of development in four categories: content knowledge, skills, dispositions, and feelings.

The purpose of this study is to understand the realities of the participants and setting throughout the execution of the curriculum. To achieve this goal, a qualitative research design was used (Patton, 2002; Creswell, 2008). Furthermore, the goal of the researcher was to gain an in-depth understanding of the phenomenon in one particular classroom. Therefore, the Case Study framework (Yin, 2009) was selected since a case study is “a study of the particularity and complexity of a single case, coming to understand its activity within important circumstances” (Stake, 1995).

Method

Curriculum development and data collection

The setting for this study is a university campus-based child care program in the Midwestern U.S., and participants are 11 children, 10 boys and a girl, their parents and the classroom teacher.

Based on initial observations of the classroom setting that had occurred a year prior to the study, desired learning outcomes, and the nature of an early engineering (EE) design-based curriculum, the researcher selected two curricular frameworks: The Creative Curriculum (Dodge and Colker, 1996) and The Project Approach (Katz and Chard, 2000). The Creative Curriculum is a holistic teacher-driven framework (Dodge and Colker, 1996), widely used in preschool classrooms. It is also the framework that was also used in the preschool classroom in which this study took place. The Creative Curriculum was selected by the researcher to establish a stimulating early engineering learning environment and to address development of selected pre-planned STEM knowledge and skills within the design project implemented through the EEC. The Project Approach is a child-driven framework designed to complement other teacher-driven preschool curricular frameworks (Katz & Chard, 2000). In the EEC, it was employed in order to complement The Creative Curriculum and to offer to the children a child-driven design project experience.

EEC consists of 24 EE lesson plans. It addresses science, technology, engineering, and math concepts and practices, all integrated within one developmentally-appropriate EE design project. The theme of the design project was “Let’s build a city,” and it was presented to the children through two puppets, Sam and Andy. The STEM content was designed to be addressed in class during teacher-led large group (LG) time, followed by children-led small group (SG) time. EEC implementation lasted 3 months, from September to December 2010. Classes took place twice a week.

Data collection for the current study included the researcher’s systematic field notes taken in class during and after the EE lessons, the teacher’s notes from class taken during the SG time, the teacher’s weekly journal, records of the children’s work, the parents’ forms.
containing demographic information and a home engineering environment survey, parents' letters reporting information gathering and EEC related activities at home, and the teacher's exit interview conducted a month after the end of the curriculum implementation.

**Data analysis**

The data in this study were analysed qualitatively using the open coding method. The first data set analysed consisted of the researcher's classroom field notes. To address the research question, namely, what type of children's STEM learning might occur as they participate in a developmentally appropriate EEC, the four learning goals as defined by Katz (1999): knowledge, skills, dispositions and feelings, were used as the four initial categories to identify. Open coding was then further applied to the data to identify and define the STEM learning subcategories. To analyse the data, researcher followed the “coding data, finding patterns, labelling themes, and developing a coding system” model as proposed by Patton (2002). Following the model presented, the researcher started with a thorough reading of the classroom field notes. During the first reading, text segments and the children's quotes indicating their instances related to STEM knowledge, skills, dispositions, and feelings were marked on the documents. In the second and third reading of the classroom field notes, specific learning patterns started to become identifiable, labels for the identified instances were created and codes regarding the STEM learning subcategories were defined. Coding definitions were then presented to an external researcher and later to a member of the research group in order to establish clarity of the definitions used. During this process, the codes were redefined to their final form. For the rest of the study, these codes will be referred to as the learning codes. The learning codes were then applied to all data. Using the learning codes, the researcher's classroom field notes and classroom work records, the teacher's notes, the teacher's journal, and the parents' letters were analysed by the researcher. Data from the teacher and the parents were used to provide triangulation.

**Findings and conclusions**

The children, as is typically the case in a preschool classroom (NAEYC, 2009), entered the classroom and participated in the EEC, with different sets of skills and strengths already developed. Knowledge, skills, dispositions and feelings (Katz, 1999), were the four initial categories of learning to identify during data analysis. The children's participation in the EEC resulted in the need to identify numerous STEM-related learning subcategories. Through further analysis of the data, and keeping a STEM perspective in mind, 15 subcategories of knowledge, 15 subcategories of skills, 5 subcategories of dispositions demonstrated mainly through children's preferences towards particular materials activities or collaborations, and 11 subcategories of feelings became apparent. Detailed descriptions of the subcategories and examples of learning instances that represent them are presented below (Figure 2, Figure 3, Figure 4, Figure 5). Not all of the instances in all of the learning subcategories were equally frequent and easy to identify (Figure 6). Some became apparent through the children's discussions with other children or with the...
teacher, and some were discernible only by careful and systematic observation, discussion, and documentation of the children's work.

Regarding the learning goals, it appears that the children's STEM knowledge and skills instances were more frequent than those indicating development of dispositions and feelings. A similar observation was also reported from the teacher and parent data. Dispositions and feelings were not reported early in the three-month period, but rather started to be noted after the sixth EE class. There are two explanations for this finding: either the children's dispositions and feelings developed up over time or it took a long time for the adults conducting the observations to be able to identify them. As time went on, children demonstrated improved understanding of the final goal and were integrating pieces of their prior work into new constructions. Therefore, this may have also worked towards the development of more observable expressions of pleasure and satisfaction.

Examination of children's participation in the EEC reveals a variety of learning strategies demonstrated by the children, as they adopted the EE content and activities to their own preferences, hopefully leading to deep levels of engagement and learning. While some children indicated deep engagement and participation during LG discussions, others demonstrated learning while actively participating in the SG hands-on activities, and a third group demonstrated learning while very observing other children's work processes and final products.

Figure 1 : Total number of instances identifying STEM knowledge subcategories as they appeared from the classroom field notes and the classroom work records
Future research

With regards to future work we propose that an expanded and more elaborate version of the EEC should be designed in addition to seeking implementation of the EEC in diverse
preschool settings. Both efforts should aid in validating the early engineering curriculum and expanding its transferability.

**References**


Acknowledgements

Acknowledgements can be made after the References. Use Level 3 Heading and Body text style. Leave one blank line after the Acknowledgements.

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Measuring Pupils’ Perceptions of Engineers: Validation of the Draw-an-Engineer (DAET) Coding System with Interview Triangulation

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Abstract: The Draw-an-Engineer Test (DAET) measures pupils’ perceptions of engineers and engineering. However, DAET data collection and analysis is inefficient, relying heavily on associated interview data requiring additional time and resources. The purpose of this study is to validate a comprehensive coding system developed to be used as a stand-alone measure of pupils’ perceptions of engineering without an accompanying interview. Participants were pupils ages 8-11 who completed the DAET and then interviewed. The study had three phases: (1) interview analysis took place to identify areas for general improvement; specifically, better DAET and interview alignment, (2) protocol implementation guidelines established and comparable DAET questions were written for the interview protocol to allow triangulation, and (3) coding results for DAETs and interviews were compared to determine reliability. Drawings and interviews matched 80% of the time, which provides evidence of validity for the DAET coding system as a stand-alone measure of pupils’ engineering perceptions.

Introduction and Background

The Draw-an-Engineer Test (DAET) is a commonly used and integral method to gather information concerning pupils’ concepts and perceptions of engineers and engineering (e.g., Capobianco, Diefes-Dux, Mena, & Waller, 2011; Fralick, Kearn, Thompson, & Lyons, 2008; Oware, 2008; Weber, Duncan, Dyehouse, Strobel, & Diefes-Dux, 2011). Though vital to engineering education studies, particularly in primary education (children age 7-11), the DAET data collection process, as it stands now, is cumbersome because its analysis relies heavily on co-collected and analyzed interview data and drawings. Such data collection requires large quantities of time and resources to provide complete information about each pupil’s DAET. This resource-intensive method often leads to smaller than desirable sample sizes.

Children’s drawings have been used in a variety of settings as a means of assessment and a method of gathering information in a non-threatening way. Children’s drawings have been used as an effective pre/post assessment (Bowker, 2007; Weber, 2008) to measure
differences in children’s perceptions (Barraza, 1999; Bowker, 2007) and assess children’s attitudes and misconceptions about scientists and engineers (Chambers, 1983; Knight & Cunningham, 2004). For a more detailed account of how the DAET has been utilized and a tested third-generation coding system, see Weber et al. (2011). These studies provide a basis for this study.

Purpose

The purpose of this study is to validate a comprehensive coding system to be used as a stand-alone measure of pupils’ perceptions of engineers and engineering, thus eliminating the need for an accompanying interview.

Theoretical Framework

It is common practice in school settings to encourage children to draw – not only in the context of art education, but also in other curricular areas. Drawing is seen as an alternative assessment instrument (Hein & Price, 1994), as an instrument to represent meaning (Wells, 1985), and as a tool to express mood (Jolley & Thomas, 1995). Social constructivists, such as Vygotsky (1962) and Wertsch (1991), posit a connection between thought and speech, arguing that verbal thought can be represented in many ways including drawings or symbols (Brooks, 2009; O’Loughlin, 1992; Wertsch, 1991). For example, Brooks (2002) used the theory of social constructivism to study children’s drawings as a “meaning-making tool” (p. 113).

Many believe that drawings are limited to artistic expression and are therefore an inadequate substitute for verbal or mathematical skills assessments. However, this proposal utilizes a theoretical framework of social constructivism to examine children’s drawings as a communication tool of equal or greater value than the more explicit communication channels such as the spoken or written word (e.g., interviews or open-ended surveys).

Methods

Procedures

To provide evidence about whether the DAET could be used as a valid, stand-alone assessment of students’ perception of engineers and engineering, this study was divided into three distinct phases (Table 1): 1) an interview analysis, 2) an interview protocol revision, and 3) a comparison of coded drawings and coded interviews. During Phase 1, the current interview protocol was closely analyzed to determine how questions related to the DAET coding system could be incorporated by focusing on time dedicated to the DAET instrument during the interview, the interviewer and interviewee dynamics, and how, in general, the protocol could be improved. In Phase 2, interview implementation guidelines were developed and additional questions related to the DAET instrument were added. Finally, in Phase 3, a quantitative comparison was made to validate the DAET coding system. The validation was conducted by analyzing the pupils’ drawings and interviews separately using the coding system and comparing the percentage of agreement.
Table 1: Research phases

<table>
<thead>
<tr>
<th>Phase and Description</th>
<th>1: Interview Analysis</th>
<th>2: Interview Protocol Revision</th>
<th>3: Triangulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation of time dedicated to interviews, interview dynamics, and general observations of Cohort 1 with treatment and control groups (n=20)</td>
<td>Five sections of DAET-targeted interview questions were added to the protocol</td>
<td>Coding of paired DAET drawings and interviews from Cohorts 2 and 3 with treatment and control groups (n=127)</td>
<td></td>
</tr>
</tbody>
</table>

**Participants**

Participants were elementary pupils in grades two through four (ages 8-11) from one school district in the south-central United States taking part in the study during Spring 2009 (Cohort 1 students), Spring 2010 (Cohort 2 students), and Fall 2010 (Cohort 3 students). The participant demographic was ethnically diverse, with pupils from both urban and suburban schools. There were 19 participating classrooms; ten were classrooms incorporating engineering curriculum elements (treatment) and nine were control (comparison) classrooms. The interviews that were analyzed were an equal number of both treatment and control schools (Cohort 1), and triangulation took place with both treatment and control groups (Cohorts 2 and 3).

**DAET Assessment and Coding System**

During assessment administration, each participant received the DAET form and a writing utensil and was told, *“In the box on your piece of paper, draw an engineer doing engineering work,”* and was allowed to draw for 20 minutes. Within that time, each pupil also answered the question, *“What is the engineer doing?”* Both the drawing and written answers to the question were included in the coding of the drawings. Following the drawing exercise, pupils were randomly selected to participate in an interview to explain their drawing and discuss their thoughts about and engineers engineering.

The DAET Coding System was developed over a series of six iterations using a grounded theory approach (Corbin & Strauss, 1990). In initial iterations, open coding of pupils’ drawings, written answers, and interview transcripts were used to develop initial categories. Next, axial coding was used to condense and refine the codes (Weber et al., 2010) while incorporating findings and recommendations from previously published research (e.g., Fralick, et al., 2008; Knight & Cunningham, 2004; Oware, 2008; Prabha & Garg, 2000; Weber, 2008).

**Pupil Interview Analysis**

As part of a larger research project, an interview protocol was developed to accompany the DAET. This protocol was intended to gather in-depth data about pupil perceptions of engineering. The first section of the protocol asked about the drawing in general; the second section focused on questions to better understand pupil perceptions of engineers and engineering. New sets of questions were added to the existing pupil interview protocol to target different categories of the DAET coding system; these additional
questions were crucial for triangulation and assessment of reliability. The five interview categories were: 1) engineer drawn; 2) tools, artifacts, and other objects present; 3) environmental component; 4) building structure and/or machine present; and 5) engineering. For example, an interview question for the engineer drawn category was “Can you point to the engineer in your drawing?” Interviews were administered by three to four individuals of varying backgrounds (e.g., university faculty, graduate students, university staff, and local school personnel) for each interview cohort.

Reliability

Drawing and interview pairs were coded. For Phase 1, only post-study interviews were analyzed as these were believed to contain more saturated information about engineering since the treatment group pupils had learned about engineering during the academic year. Both pre- and post-data were coded in Phase 3.

The drawings and interviews need to have an acceptable reliability between raters and between drawing and interview pairs (i.e., 80% using liberal measurements) before the DAET coding system can be used as a stand-alone measure. Before coding the drawings for triangulation, the interrater reliability of the research team was established using critical incident sampling, with a result of 81.7%. A liberal measure of interrater reliability calculates the percentage of agreement or correlation between raters (Krippendorff, 2009). While more liberal criteria (e.g., 0.70 agreement) are typically used for exploratory research (Lombard, Snyder-Duch, & Campanella Bracken, 2002), Neuendorf’s (2002) review of typical cutoffs for inter-rater reliability found that 0.90 is an acceptable criteria for all types of situations, and that 0.80 or greater is acceptable for most situations.

Triangulation

To create a method to triangulate pupil drawings with interviews, five interview question categories were implemented, taking approximately three to five minutes per category when added to the existing interview protocol. Figure 1 provides an example of how the drawing/interview triangulation was carried out. The figure shows a pupil’s drawing and the matching portion of that pupil’s interview transcript, along with the DAET and interview codings. The coding system responses are compared to the pupil’s interview responses to determine the percent agreement. For example, the data presented in Figure 1 show that the drawing was coded as having humans present, and the pupil interview transcript was also coded as indicating the presence of humans. When the other coding categories, which were represented here, were analyzed, 100% agreement was found between the drawing and the interview.
**Results**

Results from the three phases of this study are presented here. In Phase 1, transcripts indicated that interviewer dynamics were notably different between interviewers, where children tended to be more willing to work with strangers if they sense a connection with them, but seemed intimidated by more senior level interviewers (school personnel and/or age related), which is important to note for future modifications of the protocol. The interview analysis results showed a difference in interview length (treatment versus control group where the total length of treatment group interviews (averaging 11 minutes) were longer than those of comparison group interviews (averaging 8 minutes). More in-depth analysis of interviewer and length of time spent interviewing revealed, however, that one interviewer in particular spent less time on interviews with control group (eight minutes) pupils than with treatment group (11 minutes) pupils. The different times were used to determine the number of questions to be added for Phase 2.

For Phase 2, five categories were developed and added for phase three analysis and triangulation. In Phase 3, we found 80% reliability between the drawing and the interview (Table 2). However, reliability was difficult to achieve in some areas like “who will benefit
from the engineering” showing only 50% reliability and “where the engineering is taking place” (location) as only 30% reliable between the two methods. Interrater reliability was 88% for the drawings and 90% for the interview categories, covering 10% of the sample.

Table 2: Interrater reliability and interview/drawing reliability

<table>
<thead>
<tr>
<th>Interrater Reliability</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drawing</strong></td>
<td></td>
</tr>
<tr>
<td>Coder 1 vs. Coder 2 86%</td>
<td>Coder 1 vs. Coder 2 93%</td>
</tr>
<tr>
<td>Coder 2 vs. Coder 3 89%</td>
<td>Coder 2 vs. Coder 3 83%</td>
</tr>
<tr>
<td>Coder 3 vs. Coder 4 89%</td>
<td>Coder 3 vs. Coder 4 93%</td>
</tr>
<tr>
<td><strong>Interview</strong></td>
<td></td>
</tr>
<tr>
<td>Coder 1 vs. Coder 2 88%</td>
<td>Coder 2 vs. Coder 3 90%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interview/Drawing Reliability</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HUMANS</strong>: People in Drawing (human, object, student, name, gender, group)</td>
<td>80%</td>
</tr>
<tr>
<td><strong>HUMAN-ENGINEERED OBJECTS</strong> (vehicles, machines, tools, structures, artifacts)</td>
<td>78%</td>
</tr>
<tr>
<td><strong>SYSTEM</strong> (process, engineering language, why and who benefits)</td>
<td>67%</td>
</tr>
<tr>
<td><strong>HUMAN MANAGED</strong> (location, religion, social, political, education, science and technology)</td>
<td>79%</td>
</tr>
<tr>
<td><strong>NATURAL</strong> Abiotic (hydrosphere, lithosphere, atmosphere)</td>
<td>96%</td>
</tr>
<tr>
<td>Biotic (plant, animal, humans)</td>
<td></td>
</tr>
<tr>
<td><strong>OVERALL</strong></td>
<td>80%</td>
</tr>
</tbody>
</table>

### Discussion

In the interview analysis (Phase 1) there was a discrepancy between control and treatment group interview length; however, further analysis revealed that this difference may be dependent on one interviewer. As a result of Phase 1, future directions include revised interview protocols and techniques, as both are crucial to achieving reliable data. Interviewer training should also be conducted to help increase consistency in interviewing between treatment and control groups.

For Phase 2, questions were implemented and improved to achieve a better picture of what the pupils were saying about the drawings while staying within time constraints. Finally in Phase 3, the triangulation revealed that the DAET coding system overall shows evidence of validity and can serve as a reliable stand-alone measure of pupil’s engineering perceptions, but that specific categories still need refinement and revision as indicated by the lower than acceptable reliability of two subcategories: who will benefit from the engineering (System category) and where the engineering is taking place (Human Managed category). After these further refinements, reliability of the drawings and interviews will continue to be tested. These coding results for pupil drawings and interviews will continue to be compared to confirm that the coding is valid.

Based on the results found in this study’s Phase 1, we recommend using only interviewers who have undergone more rigorous training on the interview protocol to increase interview consistency across all pupils. Based on Phase 3 results, we can recommend the use of the coding system as a stand-alone measure of pupils’ perceptions of engineers and engineering when only the subcategories with acceptable reliability are used. Further refinements to the coding system are in progress.
Significance of the Study

This study is situated in the instrument development and refinement branch of engineering education research. The construction of an instrument and its rigorous testing for validity and reliability are crucially necessary precursors to quality research. This paper contributes threefold to the knowledge base: (1) making transparent the process of instrument development to ultimately increase the quality of engineering education research instruments, (2) simplifying the data collection and analysis associated with the DAET, and (3) contributing to the assessment community a new validation of artifacts through interviews. Additionally, this triangulation technique can be adapted to other similar tools (e.g., the Draw-a-Scientist Test; Chambers, 1983). Further research should examine the coding system in countries and cultures other than the United States.

References


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Abstract: Conducted among 73 second to fourth grade teachers who received one-week elementary engineering education training in the INSPIRE Summer Academy at Arlington, this study investigated how these elementary teachers developed their pedagogical engineering knowledge (PEK) through engineering teaching practice in real elementary classroom settings. Data collected in this study include face-to-face interviews and an online open-ended survey. Findings yielded from inductive qualitative analysis indicated that the elementary teachers’ PEK included two reciprocally interactive parts: the “knowing-about” (knowledge about engineering learning difficulties and contextual constraints of integrating engineering into elementary classrooms) and the “knowing-to” (knowledge in the form of engineering teaching strategies and methods responsive to those perceived learning difficulties and contextual constraints). The PEK development was involved in an evolving and dynamic process where the development of “knowing-about” and “knowing-to” stimulated and interacted with each other. This study revealed that understanding about elementary teachers’ PEK development will help improve future professional development in elementary engineering education.

Introduction

Integrating engineering into elementary classrooms is viewed as a means to strengthen the STEM workforce pipeline by developing among young children an interest in engineering and encourage them to consider it as a career (Wicklein, 2003; Petroski, 2003). However, the biggest challenge of integrating engineering into elementary classrooms is preparing elementary teachers for engineering teaching because of elementary teachers’ weak science knowledge, their anxiety or fear about engineering, lack of previous experience with elementary engineering education, and their skepticism about including engineering in elementary classes (Cunningham, 2008). Similar mindsets about engineering and elementary engineering education were also found among the elementary teachers in previous research on INSPIRE Summer Academy (a week-long, face to face workshop for elementary engineering education) (Liu, Carr & Strobel, 2009).

Given the lack of preparation among elementary teachers for teaching engineering, it is reasonable to believe that there is much to be done in order to provide effective professional development for elementary teachers to prepare them for engineering teaching. Although research focusing on effects of professional development yielded findings showing the positive impact of professional development on elementary teachers’ engineering content knowledge and teaching practice (Cunningham, Lachapelle
& Keenan, 2010; Hsu, Cardella & Purzer, 2010), little is known about how elementary teachers develop their PEK during their real-world engineering teaching practice after finishing their learning in professional development. An understanding of elementary teachers’ PEK development through engineering teaching practice is critical for the improvement of existing and future professional development programs in elementary engineering education. With the goal of promoting this understanding, the present study investigated how the elementary teachers of the INSPIRE Summer Academies at Arlington, TX, constructed their PEK through their engineering teaching practice.

Adopting a phenomenological approach, this study explored the lived engineering teaching experience of the elementary teachers to find out “how they perceive it, describe it, feel about it, judge it, remember it, make sense of it, and talk about it with others (Patton, 2002, p.104)” — the “it” of PEK. Conducting the study from a phenomenological perspective, the researchers conducted in-depth face-to-face interviews and an on-line open-ended survey with the elementary teachers to obtain rich descriptions of their lived engineering teaching experiences. The lived experiences of these teachers were “bracketed, analyzed, and compared” (p. 106) to identify the commonalities of PEK development by elementary teachers.

**Theoretical Framework**

From the constructivist point of view, learning is a dynamic internal process where learners actively “construct” knowledge by connecting new information to what they already know, rather than a process in which learners are passive recipients of information transferred to them from external sources (Falk, 2009), and knowledge is constructed in the mind of the learner as a consequence of working through real-world situations (Falance, 2001). As qualitative, constructivist researchers, we view learning to teach engineering and developing PEK by elementary teachers not as a passive process where they take and apply what they have learned from professional development, but as an active and dynamic process where they construct their knowledge about and make sense of teaching engineering through real personal teaching experiences. Adhering to the constructivist paradigm, we looked into the elementary teachers’ teaching experiences over an extended period for an understanding of how they developed their PEK through engineering teaching practice.

Both Students and teachers learn through situated practice (Bruner, 2004; Lave & Wenger, 1991). The situated engineering teaching practice for the elementary teachers in this study came to them after they finished the training in the INSPIRE Summer Academy. To understand their learning of engineering teaching, one needs to look into the context where the situated practice took place. According to Cunningham & Duffy (1996), “The constructivists view the learning as the activity in context. The situation as a whole must be examined and understood in order to understand the learning. Rather than the content domain sitting as central, with the activity and the „rest“ of the context serving a supporting role, the entire gestalt is integral to what is learned” (p. 171). Within the constructivist paradigm, we set our study of the elementary teachers’ development of PEK in the entire gestalt of “engineering, learners, and classroom-school contexts” (ELC). Based
on this constructivist PEK-ELC framework (see figure 1), the study was intended to present a holistic picture of the elementary teachers’ development of PEK.

![PEK-ELC Framework](image)

**Figure 1. PEK-ELC Framework**

Purpose and Research Questions

Without prior engineering subject matter knowledge and prior engineering teaching experience, for most elementary teachers, starting to teach engineering in their classrooms means the beginning of their development of PEK. Integrating engineering into elementary classrooms is a new phenomenon (Cunningham, 2008). This study was intended to reveal how elementary teachers, in this new phenomenon, developed their PEK. An understanding about elementary teachers’ PEK development will promote the development of effective professional development programs to prepare in-service elementary teachers for engineering teaching. This understanding may be able to shed light on how to integrate elementary engineering education into already tightly-packed teacher preparation programs to ensure sustainable integration of engineering education in elementary classrooms. The researchers sought to answer the research question of “how does elementary teachers’ PEK emerge in their engineering teaching practice?” Looking specifically into the areas where engineering teaching interacts with learners and with classroom and school contexts, this research question includes two sub-questions: 1) How does elementary teachers’ PEK emerge in the area of Engineering & Learner (EL)? 2) How does elementary teachers’ PEK emerge in the area of Engineering & Contexts (EC)?

Methodology

This study focused on the new phenomenon of integrating engineering into elementary classrooms. A phenomenological research method was used to explore the PEK development of the elementary teachers by looking at how it is that they experienced what they experienced (Patton, 2002) in their teaching of engineering in elementary classrooms. Data of this study were triangulated through transcripts of face-to-face interviews and answers to the on-line open-ended survey questions. PCK as teacher-specific professional knowledge is mostly tacit (Kind, 2009). The purpose of using interviews and open-ended survey as the data sources of this study was to engage the
elementary teachers in articulation and reflection of their engineering teaching experiences so as to make the tacit nature of their engineering teaching practice and the pedagogical reasons behind their engineering teaching more explicit.

Participants

The interviews of the study involved 73 elementary teachers who received one week elementary engineering education training in the INSPIRE Summer Academy at Arlington (see table 1 for demographic information) either in 2008 or 2009. A total of 101 interviews were conducted which include both individual interviews and group interviews.

<table>
<thead>
<tr>
<th>N</th>
<th>Gender</th>
<th>Years of teaching</th>
<th>Grade level</th>
<th>Instructional Facilitator (Across Grades)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>M</td>
<td>0-2</td>
<td>3-5</td>
</tr>
<tr>
<td>73</td>
<td>67</td>
<td>6</td>
<td>5</td>
<td>19</td>
</tr>
</tbody>
</table>

Table 1: Demographic information of teacher participants

Procedures of Data Collection

The face-to-face group interviews were conducted in June 2008, December 2008, and December 2009. In group interviews, the elementary teachers were grouped into groups of three to six based on their individual schedules and each group was interviewed by a member of our research team each time. The individual interviews took place in May 2009 and May 2010 respectively. All interviews were audio-taped and then transcribed. The open-ended survey was posted on SurveyMonkey in July 2009 and the survey data were collected in September 2009. The data were sorted in an Excel file after collection.

Data Analysis

The individual interview transcripts were first divided into “Title I Schools” group and “Non-Title I Schools” group. Based on the elementary teachers’ years of teaching experience, the “Title I Schools” group was divided into groups of 1, 2, 3, and 4, and the “Non-Title I Schools” group was divided into groups of 5, 6, 7, and 8. Group 1 and group 5 were “0-2 years” groups, group 2 and group 6 were “3-5 years” groups, group 3 and group 7 were “6-10 years” groups, and group 4 and group 8 were “over 11 years” groups. Three interview transcripts were randomly selected from each of the eight groups. The 24 individual interview transcripts and the answers to the open-ended online survey were first analyzed.

The principles of analytic induction were adopted to guide the data analysis process (Bogdan & Biklen, 2007) allowing the researchers to build patterns of meaning from the data (Patton, 2002). Specifically, each interview transcript and each teacher’s responses to the survey questions were treated as an independent text. Each text was read on a line-by-
line basis separately while analytical memos were taken about the patterns emerged. After the patterns were collected, comparisons were made across the patterns to form coding categories. The researchers then tested these coding categories against five transcripts randomly selected from the individual interviews and five from the focus group interviews. In the testing process, the researchers looked for further evidence that either challenged or supported these coding categories and revised these coding categories to reflect new emerging patterns. The revised coding categories were then tested again against five transcripts randomly selected from the individual interviews and five from the focus group interviews. The comparisons and revisions went on until no new patterns emerged, and the categories were saturated (Strauss & Corbin, 1998). A list of core categories was finally yielded and the researchers spot-checked the core categories against all other interviews not previously selected to ensure that the categories were truly saturated.

Findings and Discussion

In this study, the interview questions and the open-ended online survey questions were intended to allow the elementary teachers to articulate their experiences, problems, and associated solutions concerning teaching engineering to elementary students. Three categories emerged through the analysis and interpretation of these articulated experiences, problems, and solutions.

Knowing about Engineering Learning Difficulties

Teaching engineering for the first time and teaching engineering to 2nd through 4th graders who were not typically exposed to engineering, the elementary teachers in this study developed their PEK by gaining new knowledge about their students’ characteristics and learning difficulties associated with engineering learning. One thing that the elementary teachers learned through their engineering teaching experience was their elementary students’ lack of “basic knowledge of teamwork” about engineering activities. The elementary teachers also learned through their engineering teaching experience about their students’ misconceptions about engineering, their engineering learning difficulties, and difficulties related to assessing engineering learning.

In their engineering teaching experience, the elementary teachers were discovering “How are elementary engineering teaching and learning like?” “What do the students find difficult?”, “What is the source of the difficulties?”, and “What misconceptions are common?” Answers to these questions served as an important resource for the elementary teachers’ development of PEK.

Knowing about Contextual Constraints of Elementary Engineering Teaching

Teaching and learning do not happen in vacuum but in specific contexts. Practicing engineering teaching in their elementary classrooms, the elementary teachers in this study were learning about the contextual factors constrained their teaching of engineering. The contextual constraints experienced by the elementary teachers included classroom management issues, time issues, lack of administrative support, and teacher accountability.
issues. These contextual constraints caused great difficulties for the elementary teachers to integrate engineering into their classrooms.

According to Orton (1993), the “situated problem” of teacher knowledge is that it is deeply dependent on particular times, places, and contexts, and lacks the general character of knowledge in mathematics, physics, or even psychology (p. 1).” The elementary teachers in this study developed knowledge of the contextual constraints of integrating engineering into elementary classrooms. Such knowledge is related to the “situated problem” of teacher knowledge and is therefore an indispensible part the elementary teachers’ PEK developed through engineering teaching practice.

**Knowing to Deal with Learning Difficulties and Contextual Constraints**

The data of this study revealed that the elementary teachers developed their knowing about their students’ engineering learning difficulties and the contextual constraints of elementary engineering teaching. Such knowing about stimulated the development of different engineering teaching methods and strategies that were responsive to those perceived learning difficulties and constraints.

In their engineering teaching practice, the elementary teachers made engineering concepts comprehensible and engineering activities doable to their elementary students by adapting what was learned from the INSPIRE Summer Academy to specific student learning needs. The elementary teachers created new avenues of teaching engineering by making cross-curricular connections and by exploring external resources about elementary engineering education. Equally important is that these elementary teachers were creating their own engineering teaching materials and engineering activities to overcome the contextual constraints and to make elementary engineering teaching more feasible and sustainable. In their engineering teaching practice, the elementary teachers searched for and experimented with multiple avenues for teaching engineering to their students, and they made contextually situated choices about engineering teaching. Their PEK grew by knowing-in-action and learning-in-action.

**Discussion**

The findings of this study showed that, through situated engineering teaching practice, the elementary teachers developed their knowledge about how engineering teaching and learning were hindered by their students’ engineering learning difficulties and contextual constraints of elementary engineering education. According to Mason and Spence’s (1999) classification of the types of teacher knowledge, this part of knowledge is the “knowing-about.” The “knowing-about,” though important, is not sufficient for a teacher to handle particular learning and teaching situations. Teachers need to develop “knowing-to,” which is the tacit knowledge required to respond and act in specific context or situation. As is shown by the findings of the study, the elementary teachers developed their “knowing-to” by experimenting with various methods and strategies to deal with those learning difficulties and contextual constraints they experienced in their engineering teaching practice.
The elementary teachers' PEK included two parts: the “knowing-about” part and the “knowing-to” part. These two parts were developed in the area of EL where engineering interacted with learners and in the area of EC where engineering teaching interacted with classroom and school contexts. The PEK development was involved in a dynamic process where the “knowing-about” and the “knowing-to” stimulated each other. This evolving and dynamic process can be illustrated as is shown in Figure 2.

Conclusions and Implications

The elementary teachers in this study developed their PEK through real-world engineering teaching. Teachers' PEK included both the “knowing-about” part and “knowing-to” part in the areas of EL and EC. The development of “knowing-about” and “knowing-to” took place in a dynamic process deeply situated in real elementary classroom settings. The elementary teachers' situated and practice-based knowledge concerning elementary engineering teaching are precious resources that can be used for the improvement of future INSPIRE or other professional development programs in elementary engineering education. The findings of the study suggest that a “returning, sharing, and improving” mechanism can be adopted by professional development programs to better prepare both in-service and pre-service elementary teachers for elementary engineering teaching. The mechanism can work like this: Invite those who previously attended the professional development programs and have practiced engineering teaching in real elementary classrooms to return and share their “knowing-about” and “knowing-to” with new participating teachers. This will help the new participating teachers improve their engineering teaching once they start their engineering teaching practice. Professional development faculty and organizers can improve instruction and training materials for their future participating elementary teachers based on the “knowing-about” and “knowing-to” gathered from their previous participating teachers. The “knowing-about” and the “knowing-to” in the area of EC would be especially important for professional development programs if they aim to permeate...
engineering into in elementary classrooms. The “knowing-about” and the “knowing-to” in the area of EC, for example, would help professional development programs to ensure that the elementary engineering lessons or activities they develop are aligning with what elementary teachers have to teach as mandated by state or school curricula. Another possible way of support is to invite pre-service teachers to attend “returning, sharing, and improving” sessions, which will facilitate pre-service teachers’ future development of PEK and prepare them for possible issues they may encounter in their future elementary engineering teaching practice. It is envisaged that future research will investigate how findings from this study can be utilized to promote professional development in elementary engineering education.

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Session 6: Friday morning

Topic: Assessment 2 – Chair: Erik de Graff

(Re-)Building an Assessment Paradigm: Individual Student Learning in Team-Based Subjects

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Abstract: The assessment of individual student learning within team-based subjects is often a challenging task, due in part to the high levels of complexity inherent in the socially mediated and socially determined team-based learning environment. This paper will describe the design and current status of a two-year funded research project. This multi-university design-based research activity is investigating and constructing a strategic paradigm for the assessment of individual student learning in team-based subjects – a paradigm which supports the cooperative creation of learning intent and performance expectations between academic staff and students.

Introduction

The assessment of individual student learning within team-based subjects is often a challenging task, due in part to the high levels of complexity inherent in the socially mediated and socially determined team-based learning environment (Parsons, 2004; Bourner, Hughes, and Bourner, 2001). Typically, instructors attempt to use team products (such as team project reports or presentations) as evidence of individual student learning (Fellenz, 2006). This practice, often melded with peer assessment processes, presents a number of challenges for effective assessment of individual student learning—including social desirability effects in both team product development and in self-peer assessment. In response to the wide variety of assessment practices utilized in team-based learning environments, our research project was designed and implemented in order to derive an assessment framework which allows individual students to effectively demonstrate their learning in the team-based learning environment.
Research Context

This research and development project was funded in 2009 by the Australian Learning and Teaching Council, involving 5 institutions: CQUniversity (Australia), Aalborg University (Denmark), Swinburne Institute of Technology (Australia), Victoria University (Australia), and University of Melbourne (Australia). Each of these institutions offers team-based engineering subjects. For CQUniversity, Aalborg University, and Victoria University, these subjects are offered within a larger project-based learning approach, the configuration of which varies across the universities. For Swinburne Institute of Technology and University of Melbourne, team-based subjects are offered ad hoc and according to the interests of individual academic staff. By combining these varying contexts, the research team hoped to gain a more inclusive and nuanced perspective on both the assessment context in team-based subjects and possible solutions that would work across these contexts.

Methodologies and Methods

The initial overarching question driving this research project was deceptively simple: What combination of teaching practices can effectively assess individual student learning in team-based subjects? In order to investigate this question, the research team devised a staged research and development design:

1. **Conceptual model development.** This stage involved data collection and analysis, engagement with the literature, and reflective dialogue and writing by the research to construct an initial conceptual model of effective assessment of individual students who are learning in teams.

2. **Development of the strategic assessment framework.** Based on the conceptual model, the research team has developed an assessment framework (teaching practices and artefacts) that can support academic staff in assessing individual students strategically within a single subject.

3. **Implementation and evaluation of the assessment framework and conceptual model.** The final stages of the project, which are currently underway, involves implementing the framework with academic staff participants at four Australian universities and gathering data which can assist in the evaluation of the framework and the underlying conceptual model.

Conceptual Model Development

This first stage was strongly founded in a constructivist epistemology (Savery and Duffy, 2001), with the understanding that the complexities underlying effective assessment of individual student learning in team-based subjects could only be investigated and understood through gathering multiple perspectives from individual teaching practitioners as well as from students, administrators, and other stakeholders. To this end, we interviewed academic staff and students at each of the five member institutions. These interviews were transcribed and the research team conducted a preliminary thematic analysis (Boyatzis, 1998) regarding the considerations, constraints, and opportunities that
various stakeholders reported in terms of assessment in this context. These results were then discussed in light of key literature sources and the professional observations of the research team members themselves, an ongoing research team discussion that directly lead to the development of a conceptual model which captured one perspective on effective assessment of individual student learning in team-based learning environments (see Figure 1 below).

![Conceptual model](image)

**Figure 1. Conceptual model which underlies the current strategic assessment framework.**

The conceptual model is founded upon strong constructive alignment (Biggs and Tang, 2007) of the subject’s learning outcomes, teaching and learning activities, and assessment items. We suggest that ambiguous alignment between these elements in the design and implementation of a subject can create a context where both instructors and students may hold multiple and mismatched visions of the purpose, methods, and goals of assessment within that subject.

Learning outcomes are at the heart of the conceptual model and can serve as the intellectual contract between students and instructors, delimiting the knowledge and skills to be mastered. The model calls for ongoing dialogue between instructor and students which utilizes the subject learning outcomes as a navigational tool. This dialogue helps students take ownership of their own learning processes through instructors supporting individual students in creating their own evidence of mastering the learning outcomes as well as instructors supplying feedback to both individuals and teams in terms of their relative engagement with and achievement of the learning outcomes. Finally, a prioritization of the subject's learning outcomes as well as pre-determined performance levels for each learning outcome serve as the basis of assigning the final grade.
Development of the strategic assessment framework

The process of moving from the conceptual model to the strategic assessment framework involved two fundamental activities: 1) the formulation of a set of founding principles which captured the values and beliefs embedded in the conceptual model, and 2) the development of a set of teaching practices and related artefacts which can support academic staff participants in embodying and implementing the assessment framework with students.

To date, we have formulated nine founding principles which can help instructors detect and assess individual student learning in team-based subjects. As the following examples illustrate, these principles help delimit both evidence of learning and the assessment context itself:

- Team products, such as reports and presentations, by themselves provide insufficient evidence of the breadth and depth of an individual student's learning.
- Assessment of learning teams at the university should differ significantly from the product-driven focus of working teams in industry by valuing individual and team learning over "successful" completion of project assignments.
- An individual students' final grade should emphasise their final state of learning rather than indications of learning at various points during the term. While feedback may be given for work during the term, assessment of learning should be conducted via a folio of evidence presented at the end of the term.

While the current framing of the founding principles may sound too brief and proscriptive, the ultimate intention for this project is to capture and frame a paradigm for effective assessment of individual student learning in engineering team-based subjects. We expect that a key deliverable from this project will be a more fully realized description of both the founding principles and the strategic assessment framework.

From these founding principles and the processes outlined in the conceptual model, the research team created a sequence-driven assessment framework which creates clarity between instructors and students about the relative importance within multiple streams of subject content while creating the conditions for effective assessment.

Two artefacts play pivotal roles in this assessment framework: the performance standards and the grading rubric (see Figure 1). The performance standards describe key quality differences for student evidence of learning for each grading level and for each learning outcome. These standards allow students to better understand the learning outcomes themselves by describing standards of evidence for each outcome in terms such as fail (insufficient evidence), pass (sufficient evidence), good (strong evidence), and excellent (exceptional evidence). The grading rubric prioritizes the learning outcomes and lists the level of evidence needed for each learning outcome in order to be awarded a particular grade.

The dialogue between instructor and students about these artefacts serves to highlight the strategic nature of this framework. Through writing the performance standards and then
helping students to understand them, the instructor prepares students to present quality evidence that is tailored to the subject’s learning outcomes. Through writing and discussing the grading rubric, the instructor helps differentiate the knowledge and skill that are essential to progression from content that is useful but not essential. These two artefacts are introduced to students within the first two weeks of the term, making the assessment process as clear as possible while creating opportunities for deeper exploration of the subject learning outcomes.

Implementation and evaluation of the assessment framework

Currently, we are piloting the assessment framework in engineering subjects at four Australian universities in the second half of 2011. Academic staff participants (11 instructors across the four Australian institutions) are writing the performance standards and the grading rubric and introducing them within their subjects. To better frame the evaluation of this piloting, we have turned to design research, as constructed by Ann Brown (1992) and Allan Collins (2004). This research approach attempts to better understand teaching and learning practices in naturalistic settings, rather than the controlled environment of a laboratory. In our approach, we have created our framework and related artefacts and we are using their implementation in the classroom to explore the following:

- Can our academic staff participants use the founding principles, assessment framework, and artefacts to assess individual students’ learning in a manner that is both acceptable and useful?
  - What challenges do they encounter?
  - What elements in the framework do they embrace and what elements do they ignore?
- How do students experience this assessment framework and do they report any challenges or opportunities in comparison to other approaches?
- Our different participants will adapt the framework to their own teaching styles and the practicalities of their own teaching situations. How do the varying instantiations impact the perceived value and the intended purpose of the framework, artefacts, and principles

At this beginning point in our Term 2 2011 pilots, we are happy with the diversity of our academic participants and the engineering subjects they are using to pilot the framework. Our academic staff participants range from relatively new instructors to those with more than two decades of teaching experience. The subjects range from small class sizes to those with more than 100 students. Academic staff participants are expressing great interest in the two artefacts and their use, suggesting that the assessment framework holds great promise for improvements in assessment in general, as well as for more effective assessment of individual students’ learning in team-based subjects.

In the next few months, we will collect data on academic staff participants via online surveys, observational notes by research team members, and final interviews. In addition, we will collect data from students about their impressions about this approach to assessment.
Conclusion

In most university contexts, engineering students receive individual grades and individual degrees. To this end, it is imperative that instructors implementing team-based pedagogies such as PBL employ assessment methods that are transparent to students, outcomes-based, and effective in terms of assessing the breadth and depth of individual student learning. This is doubly true when we acknowledge the powerful role assessment plays in motivating students’ engagement with their own learning. As researchers and educators, we are looking forward to learning about the affordances and the limits of our assessment framework: the opportunities for better teaching and learning, the challenges of implementing it in a variety of settings, and our participants’ perspectives regarding what makes for effective assessment of individual student learning in team-based engineering learning environments.

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Considerations on the success rate in aeronautical engineering studies in Spain

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Abstract: The relationship between different learning evaluation methods and the academic success in an aeronautical engineering degree in Spain is analysed. The study is based on data about the evolution of academic achievement obtained along the last ten year, along which the evaluation and learning’s methods have suffered huge changes.

Introduction

In this study we analyze the academic success of aeronautical engineering students enrolled in ETSIA (Escuela Tecnica Superior de Ingenieros Aeronáuticos), as well as its relation with the different learning evaluation methods used. In the last few years the status of ETSIA has dramatically changed, from it being the only centre providing an aeronautical engineering degree in Spain, to it nowadays being one of several centers devoted to the teaching of this subject. This fact, along with the introduction of the new European Higher Education Area and the European Credit Transfer System, has introduced huge changes, especially in regard to evaluation methods. Instead of a unique final test, which was the mainstream option ten years ago, most subjects of the new degree have chosen either a very frequent assessment system based on weekly tests or a system based on a few (typically between three or five) midterm exams. It is important to remark here that this last option has been the usual method used to examine Spanish students in high school.

We present data about the evolution of academic achievement, depending on different study curricula and evaluation methods, and also a survey measuring the students’ perception of the convenience of each evaluation method in terms of both the learning process and workload.

At the same time of these changes, ETSIA staff has launched a series of initiatives aimed at improving educational outcomes (see Hilario, J., Ramírez, J.et al., 2008, Ramírez J., Burgos J. et al., 2008). Their academic impact is also discussed.
The paper focuses on the first cycle of the degree, where subjects are common to all students, while the second cycle include many specialties. This fact represents a diversification of studies and complicates the combined comparison of the academic results.

**Description of evaluation methods**

In ETSIA, from the year 1997/98 different methods of evaluation have been implemented in a progressive way in the first cycle of the degree.

One of the main problems of the implementation of these new methods has been the high number of students per class (around 70-100), so the help of new technologies, like optical readers or interactive response system (see Ramírez J., Burgos J. et al., 2007, Ramírez J., Burgos J. et al., 2008) have made an essential contribution.

**Evaluation methods**

**Method 1: Continuous evaluation that allow passing the whole subject (releasing tests)**

This method has been implemented from 2005-06 in two subjects of the first year of the degree (see Hilario, J., Ramírez J.et al., 2008). Nowadays this method is the most used in the subjects of the first year.

Each week or each two weeks (depending on the subject), the students have to carry out with a short test (around 20-30 minutes) with practical questions about the part of the subject explained along the previous week (or two weeks). Each question of the test has three possible answers. The mark of the correct answer is +1.5 and the mark of the incorrect is -0.5, to avoid good marks for random answers. The tests are corrected using an optical reader.

If the student has a medium mark during the year upper a minimum (normally the minimum is around 6 or 7 if the maximum possible mark is 10), then he/she pass the subject and he/she doesn’t have to carry out with a final test, unless he/she wants to improve his final mark.

If no more tests were performed, around the 20-25% of students would pass the subject by continuous evaluation. To increase this percentage, different options are used, depending on the subject. One option is to consider only a part of the tests (those with better marks) to calculate the final mark. For example, if there are 10 tests along the year, only the seventh with best mark are used to calculate the medium mark. Another option is to perform extra test (for example one extra test per each two or three tests, which includes the parts of subject considered in those tests), which provide a second opportunity for student to improve the mark they obtained in some of the tests.

If the student doesn’t obtain the minimum mark to pass the subject, then he/she has to carry out with a final test, and the mark he/she obtains by continuous evaluation is considered as a bonus (if is higher than 5) when the final mark is calculated.
The main advantages of this method are:

- Students have to follow a continuous rhythm of study along the course, and they have to pay more attention during the classes.
- If they pass the subject with the continuous evaluation, during the period of final tests they can be dedicated to the tests of other subjects.
- To facilitate the coordination when there is a high number of groups. For example, in the year 2010-11 there have been 10 groups in the first year. This method imposes a rhythm of the subject that all the teachers have to follow, because all the students of the first year have to carry out with the same test each week or two weeks.

The main disadvantages of this method are:

- To prepare and correct so many tests involves a lot of work for teachers.
- If this method is implemented in more than one subject the students are under a lot of pressure every week. As well shows in Olarrea, J., Lapuerta V. & Sanz, A. (2011), although students recognize this method is good to learn they don’t like to have so many tests along the course.

**Method 2: Continuous evaluation as a bonus**

This method was implemented in 1997-98 in two subjects of the first year of the degree. Nowadays it is used in some subjects, but it is less popular than method 1.

The methodology is very similar to the previous one. The main difference is that here the student always have to carry out with a final test, and the final mark (FM) is the mark obtained in the final test (FTM) plus a bonus corresponding to the medium mark (MM) obtained through the continuous evaluation. For example, the final mark could be calculated with an equation like this: \( FM = FTM + 0.2 \times MM \).

The problem is that this method has the same disadvantages than method 1 and less advantages than method 1, because the motivation of students to follow the continuous evaluation is lower than in method 1.

**Method 3: Midterm exams**

With this method we refer to some tests (tree or four as maximum) along the subject that allow the students to pass different parts in which the subject has been divided. As we show in Olarrea, J., Lapuerta V. & Sanz, A. (2011), this is the method preferred by students.

**Method 4: Final exam**

The students have only a final test where they are evaluated of the whole subject. Up to the last ten years, despite seeming unfair to evaluate the whole course in an unique event, this has almost been the only method used in the ETSIA. Needless to say, this is the least valued of all them by the students.

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Analysis of success rate

Any student has two chances to pass a subject along the course. The success supposes that the student has reached the minimum qualification in one of them, while the failure supposes not. The failure may occur if the student has not submitted the final assessment test (not presented) or if he/she has not reached the minimum qualifications required to overcome it (failed). To measure the student’s rate of success/failure the following ratios have been defined for each full course, distinguishing between the number of years that students have been enrolled in the center.

Success (year) = \frac{\text{Number of calls successfully overcome in considered year}}{\text{Number of students in considered year}}

Failure (year) = \frac{\text{Number of calls not passed (not presented or failed) in considered year}}{\text{Number of students in considered year}}

Figure 1 (a), (b) and (c) shows the success and the not success (failure) results in the first three years in absolute values while Figure 2 shows these results in relative values.

Figure 1 (a), (b) and (c) have also a separated representation of both cause of failure: not presented or failed. The term “not presented” is used as a direct translation of the Spanish term "no presentado", indicating both the student did not show to the final exam (if this is the case) as the incomplete status in the other evaluation methods, i.e., when he has not performed any of the tasks required.
Figure 2: Rate of success/not success (failure) during first three years in relative values.

It can be observed a clear difference in the evolution of the rate of success/failure depending on the current year. The most striking values appear in the first year. In this year the success rate evolves from 3.03 in course 2001-02 to 6.79 in 2009-10, which represents an increase of 124% in ten years. On the other hand, the failure rate evolves from 12.37 during 2001-02 to 5.09 in 2009-10 and fell by 58.9%.

In fact, in 2009-10 is achieved for the first time that the number of passed subjects is greater than not passed subjects. The same analysis in the next two years shows that the success and failure ratios remain stable. The student reaches a steady state and manages to overcome roughly the same number of subjects per year.

Figure 3: Average rating during the first, second and third year.

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On the one hand, the most difficult subjects of the degree accumulate in the second year, which justifies in part the slight decline of the success rate observed, but also the lack of appropriate advisors in the academic environment makes our students overenroll for courses they cannot adequately follow. The number of subjects in the syllabuses is too large and our students are not able to organize.

Further evidence of the results efficiency is shown in Figure 3, which represents the values of the mean scores obtained by students during their first four years in the ETSIA. These values have been obtained using the following numerical rating: 1 = passing (aprobado), 2 = good/very good (notable), 3 = excellent (sobresaliente) and 4 = outstanding (matrícula de honor), with Spanish terms in brackets.

Figures 4 and 5 show an example of particular outcomes in subjects for the first and second years. Each of the subjects depicted follow a different evaluation method: in A, method 2 until 2004/05 and method 1 later; in B, method 4 until 2005/06 and method 3 later; in C, method 4 performing a classical constructed response test until 2009/10 and in D, method 4 performing a selected response test with multiple choice from 2005/06.

Figure 4: Success and not success ratios in sample subjects with evaluation methods 1 and 2.

Figure 5 shows that subject C, which has not incorporated any innovation in his evaluation methods nor in the test style, has not improved the success rate of students, while subjects A, B and D have made an effort to adapt to the changes in the learning and evaluation process, which seems reflect in an remarkable increasing on the success rate. However, from a statistical analysis performed with the available data, it has not been possible to find a direct correlation between improvement in the success rate and the evaluation method, which seems to indicate that other factors, such as budgetary control and/or educational administration guidelines, could also be involved.
Figure 5: Success and not success ratios in sample subjects with evaluation methods 3 and 4.

Conclusions

One can think of a number of factors that influence the acquisition of knowledge by students. Much of these factors are directly related to the educational environment in which lessons are taught, while others, including those more personal are alien to that environment. The evaluation methods are a priori relevant factors of the first kind, having gathered in this study the most common assessment methods in the first cycle of the degree in aeronautical engineering.

Given the results above, there is no doubt that the academic performance in Aeronautical ETSI has experienced a remarkable improvement in considered years. Although the method of evaluation has been one of the factors contributing to this improvement, others such as budgetary control and/or educational administration guidelines should not be ruled out.

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Assessing individual performance within group design and group problem-solving learning environments

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Abstract: This paper is focused on the educational context of students learning how to be effective members of design teams in subsequent professional life, and on the means of assessing the individual students’ development of relevant abilities. Team design has become recognised as a dominant environment in which complex and innovative engineering designs are developed and resolved. Governments’ progression from “knowledge society” policies to “Innovative Society” policies give added emphasis to the need for all graduate engineers to have well developed team-work abilities in order to contribute effectively to innovation through design teams. Group problem solving techniques, such as problem-based learning (PBL) and Project-Based learning methods, are increasingly adopted into engineering education to satisfy demands for relevance to this crucial aspect of professional design practice; however, customary assessment of group achievements by allocation of group marks (equally) to individual members fails to recognise each individual’s abilities in a significant skill field, but also causes dissatisfaction among students who want their individual contributions recognised, and student satisfaction is increasingly important to accreditation and quality assurance reviews. A significant obstacle to individual assessment in group environments has been lack of definition of individual attributes that contribute to affective group/team performance, and consequent lack of verifiable criteria for measurement of those attributes in individuals. This paper draws on recent research into team design dynamics in industry, and provides criteria for verifiable assessment of individual performance in group work that is entirely transparent and meets both quality assurance and student satisfaction, as well as relevance.

Introduction

The following discussion is focused on the educational context of learning how to be professional in a team. This learning how to is generally undertaken in groups formed to
learn how to solve various types of problems. In some cases (but by no means all), the problems faced by the groups are design problems or projects; in othersthey are problems of acquiring knowledge in order to be able to contribute to individual or group design projects. We therefore use the term "group" as a generic term when referring to student work, and "team" when referring to professional activity.

**Industry and professional contexts**

Team design is a crucial environment for the resolution of complex technical challenges, and for development and resolution of complex and innovative designs in industry, and is the dominant working environment into which engineering graduates will enter [1]. Design teams in industry can consist of members from the same general discipline (eg, civil engineers) but with differing specialisations; for example, the design team for a road bridge is likely to include geo-tech specialist engineers (foundation conditions), structural specialists (steel or concrete bridge frame), and highway design specialist (for the roadway carried by the bridge). Design teams may also be cross-disciplinary, consisting of members from many different engineering disciplines, for example in the design of a new light rail (tram) system, involving mechanical, electrical and hydraulic engineers (the train), civil engineers specialising in track and bridge design (the track), and electrical engineers specialising in power distribution and pick-up systems, all working collaboratively and cooperatively in a design team to achieve a single coordinated complex design. Then there are multi-disciplinary design teams, for instance in the design of high-rise buildings, involving architects, structural engineers specialising in earthquake-resistant structures, mechanical engineers specialising in high-speed elevator systems, fire control specialists, interior designers (and many more) all having to work collaboratively and cooperatively in a design team to achieve a single coordinated complex design [2].

Application of rapidly advancing technology adds to the need for collaborative and cooperative design teams and for increasing diversity of team members. For instance, use of carbon-fibre to replace metals in motor vehicles and aircraft increases the need for team-design approaches involving various specialist engineers, and for the design team to include specialists from the fabrication and assembly trades.

Notwithstanding that there are various types of design teams comprised of differing mixes of specialists, achievement of a successful outcome depends on the same sets of qualities in the team's members. Apart from the specialist knowledge expected of a member, collaboration, cooperation and coordination have been identified above as essential achievements of the team, and these achievements require these abilities (among others) in all team members.

**Educational context**

Until recently, learning to work in teams was considered to be part of experience to be gained after graduation, but before registration. More recently, however, there has been increasing recognition of the importance of this aspect of professional practice and of the need for team-work abilities to be developed before graduation. This recognition is derived in part from the "relevance-to-practice" agenda for accreditation, and partly
from expectations that graduates will be “practice-ready” as soon as they graduate; that is, reliance on learning these abilities from practical experience after graduation (e.g., internships) is no longer acceptable.

Recently in engineering education, group-learning has been increasingly adopted to varying extents, ranging from individual projects to whole courses, and generally identifiable with established group-learning methods such as Problem-Based Learning and Project-Based Learning [3]. Reasoning for these adoptions is primarily to increase relevance of the respective courses to “real-world” practice. An associated tacit assumption is that experience of group work develops design team abilities appropriate to real-world design team environments.

However, mere participation in group problem-solving is ineffective unless it is underpinned by understanding (by the student) of the abilities they are expected to demonstrate, and unless acquisition of those abilities is verified by assessment.

As it is, group learning is rarely accompanied by strategies for development of understanding of the group dynamics involved (and individual contributions to those dynamics), and rarely by assessment strategies that identify and verify individual achievement of group-member skills. Customary practice is to assess the group’s product (design or solution to a technical challenge or problem), and to allocate the group’s assessment grade equally to all members. Thus an outside observer (e.g., an employer) cannot determine who has these abilities and who does not. At one level of consequence, this “one size fits all” practice causes dissatisfaction among students who want their own contributions recognised in individual marks, particularly those who feel that they have been disadvantaged by other individuals who have contributed less or who have disrupted the affective potential of the group and its products. At another level, this dissatisfaction is an increasingly important consideration as student satisfaction scores are crucial components of governments’ quality assurance requirements.

At a third level, course objectives (develop teamwork abilities) set out in the course handbook imply development of individual teamwork abilities, however the salient abilities are rarely identified or differentiated in the curricula and rarely assessed on an individual basis. Consequently, there is an absence of alignment between course objectives (to develop individual teamwork abilities), learning methods (involvement in group or team work) and assessment (verification of individual achievement) and, therefore, failure to satisfy the most basic requirement of quality assurance: alignment between objectives, curriculum, assessment and outcomes. Assessment of group-member skills must be on an individual basis if alignment is to be achieved, and if student satisfaction is to be achieved, and if quality assurance criteria are to be met [4][5].

**Dynamics in design teams in industry**

In order to define teamwork abilities in students, and to be consistent with pursuit of relevance of education to professional practice, we must first identify team dynamics required for effective design practice in industry; that is, dynamics that are conducive to optimal progress towards an optimal design outcome. However we must also
recognise that the dynamics in a group learning environment differ in some significant aspects from the dynamics in a design team in industry; that is, experience in group learning environments in engineering education is not the same as experience in design teams in industry; experience in group learning is therefore insufficient preparation, on its own, for work-readiness after graduation. The particular differences will be discussed later; first we need to understand how design teams work in industry.

**Relevant research**

Two research programmes of linear studies, one by Anthony Williams of engineering design teams working on complex industrial products in Australia [6], the other by Paola Michialino of multidisciplinary teams of architects, engineers and lay people working on inner city renewal projects in France [7] shed new light on dynamics of team design environments in industry. For present discussion purposes, the dynamics of design teams studied in both programmes are typical of design teams in general.

Williams’ studies used electronic audio and video surveillance facilities (with the consent of those being surveilled) and subsequent content analysis (using methods from social anthropology) to study the team dynamics and individual behaviour and contributions throughout the long-term design process. Each design team was formed for the design of a new generation of railway engine: one for a diesel-electric long-distance heavy freight locomotive; the other for a new generation metropolitan light-rail electric self-propelled carriage (aka a tram). Team members included professional engineers of various disciplines (mechanical, electrical, etc) and specialisations within those disciplines (traction, power generation, hydraulics, control systems, etc), as well as industrial designers, experts from the assembly lines, and management.

Michialino’s studies used historical congruence analysis of documents (including interviews, official reports, newspapers, video and photos) to trace the dynamics of seven design teams, each working on one of seven urban renewal projects, and each involving design of road and traffic realignments, utility relocations, pedestrian access, parks and plazas in cities in northern France.

Both studies showed (unsurprisingly) that optimal progress requires cooperation and collaboration across the entire membership of a team or group, including respect for overall design policy with respect to generic design objectives for the completed, operational project, including such relative priorities as (in Williams’ cases) operating efficiency, operational reliability, introduction of innovative technology, assembly constraints, sourcing of components (eg, local or imported), initial cost constraints, and life-cycle costs and (in Michialino’s cases) social benefit, economic cost-benefit, respect for heritage, minimisation of pedestrian/traffic conflict and danger, and legal feasibility.

Both sets of studies also showed that optimal progress requires recognition and acceptance of an optimal design sequence; for example, in the design of a light-rail carriage, should the passenger access system design (doors, steps, corridors, seats, windows, etc) be settled before or after the structural chassis and carriage envelope design are settled? And in the design for renewal should pedestrian access be resolved
ahead of traffic and utility rerouting? This sort of question depends not only on the respective design optimals, but also on the degree of interface or inter-dependence between the respective design elements. In the light rail case, if passenger access is expected to be optimal (e.g., ergonomics, anthropometrics) how much room is left for carriage frame elements? In the urban renewal case, if pedestrian access is optimised, is there sufficient space for traffic optimisation (or vice-versa)?

Another example from industry is the introduction of new technology such as carbon-fibre body and frame components for aeroplanes and cars, which must be glued together under heat; does the assembly factory have the technology for this type of process?

In any complex technical design many such interfaces emerge during the design process and they determine the subsequent sequence in which the overall design must proceed. Thus, no individual member can proceed unilaterally towards an optimal design for his or her specialist part of the project; the whole team or group must be prepared to work collaboratively and cooperatively towards optimal sequence and optimal outcome of the whole project. Any “independence” from the collective objectives contradicts the team/group design approach, and is disruptive to optimal progress and outcome.

Perhaps more significantly, the studies showed that multiple means of communication are essential to mutual understanding, collaboration and cooperation across the whole team or group [8]. That is, conventional use of traditional paper plans or transmission of on-line computer diagrams is invariably ineffective to team-wide understanding unless it is accompanied by multiple additional communication methods such as verbal and nonverbal description, and presentation of models and examples. These multiple methods of communication must usually be engaged simultaneously, and then successively augmented by additional methods in order to achieve the full understanding across the whole team that is essential to optimal team performance. Also, conventions of graphic representation and technical language differ significantly between specialisations and between disciplines, and individual members come from differing cultural, language and experience backgrounds, all of which must be accommodated in order to achieve adequate understanding, cooperation and collaboration.

Finally, the studies showed that leadership of the team changed frequently regardless of who was the official chair of team meetings. Effective progress of the team was shown to depend on group acceptance of a form of “moving” leadership according to the particular element being considered and the respective specialist input involved. Which brings us to the question of leadership.

Leadership

Leadership abilities and teamwork abilities are often confused, and some engineering programmes have introduced leadership courses to prepare students for the collaborative aspect of the professional working environment; however leadership and teamwork are separate constructs: leadership ability per se is not equivalent of teamwork ability [9],[10]. To put it bluntly, a person cannot be an effective leader until that person is an effective team member; that is, development of leadership ability should be on a
foundation of thorough a priori understanding of effective team dynamics (not vice-versa). In order to understand relationships between leadership abilities and effective group membership abilities, we will discuss leadership abilities further, but not until after we have addressed effective team membership abilities.

**Individual contributions to effective design team performance**

The above studies by Williams and Michialino, and earlier studies by Cowdroy [11] all showed that individual contributions to effective design team progress and outcomes may be defined in terms of seven differentiated individual abilities as follows (in approximate order of importance to team effectiveness):

**Ability to use multiple means of communication** to convey ideas to other members unfamiliar with the technology, or terminology of the respective member’s own area of expertise. This includes use of technical and non-technical language, non-verbal (eg, sign-language) communication, drawings, computer graphics, photos, models, and examples, often in various combinations, to communicate ideas across barriers of misunderstanding. This was found (by Williams and Michialino) to be the most important factor contributing to successful progress of any team. In addition to differences in technical knowledge, experience and terminology between members, language and cultural differences have to be overcome, and combinations of various means of communication was found to be a primary strategy for achieving productive progress. Traditional reliance on drawings to encapsulate all necessary information for understanding is therefore very unrealistic; so is current reliance on computer graphics as the dominant means of communication of ideas and details. This is a most important issue in relation to globalisation of design teams and increasing reliance on electronic communication.

**Ability to lead discussion** when the dominant issue on the table at the time is within the individual’s area of expertise; that is, when the member’s authority is “given” by the dominant issue (ie: issue-based authority). In this respect it must be accepted that the expertise of an individual member will be dominant at some times and of secondary or peripheral concern to discussion at other times. This ability is closely related to one aspect of leadership, as discussed later, as it requires both the ability to lead discussion at that time, and the ability to have the respect of others towards the relevant individual’s expertise. Ability to effectively lead discussion, even briefly, also incorporates particular qualities of balanced self-confidence; that is, neither over-confidence nor under-confidence. Over-confidence refers to autocratic, self-righteousness or domineering behaviour, or claiming knowledge that the member does not have; under-confidence refers to failure to apply the member’s knowledge and experience by failing to take initiative to provide the rest of the team with necessary information about opportunities, causes and effects within the particular member’s field.

**Patience and persistence** until the team as a whole understands the ideas the member is trying to express, and patience and persistence to try various approaches to understand what other members are trying to express. This ability is often closely related to ability to use multiple means of communication. “If at first you don’t succeed, then try, try again” is an old adage that applies here: if one means of communication or combination of means
(eg, drawings combined with verbal description) does not achieve adequate understanding, it is imperative that additional means and other combinations are progressively used until adequate understanding is achieved. And if that still does not work, it may be necessary to arrange a “break-out” from the meeting for a more intensive study of the issue, for instance where design professionals visit the assembly line to understand a particular issue of construction or assembly.

**Ability to follow**, ie to accept the advice of other members (regardless of the others’ professional or occupational status) when those members’ expertise is most relevant to discussion, ie when the issue-based authority is elsewhere. This means to listen and learn from other members in order to be able to identify technical conflicts and consequences, in terms of the present design process, subsequent fabrication and long-term performance of the design product.

**Ability to consider and generate alternative approaches** in the interest of achieving consensus and optimum progress towards an optimum outcome. This is possibly the most important individual professional/technical ability because it contributes to the core purpose of having a design team. In the early stages of design, various ideas must be “floated” from various members so that the most likely agglomerations of ideas from all members can be identified for further development and refinement. Then, during the process of development and refinement, every team inevitably reaches impasses where a proposal in the best intent from one part of the team can be seen to contradict proposals from other parts of the team, or where the consequences in manufacture or in longer term operation of the product are likely to be less than satisfactory. In such situations, in order to move forward, it is necessary for all members to be able to consider alternative suggestions from other members in terms of consequences in their own fields of expertise, and to put forward alternative proposals from the respective field of expertise that might help to achieve a new consensus and overcome the impasse.

**Ability to abstain** (but maintain engagement with the team) when discussion is about matters outside the particular member’s area of expertise. This ability is sometimes referred to as “being a good listener”, and is closely related to balanced confidence referred to above.

**Ability (flexibility) to move freely between roles of leader, follower and abstainer**, sometimes from minute to minute within a meeting, as discussion flows from one focus to another and as issue-based authority passes from member to member. Every team meeting changes focus from time to time as one issue impinges on another, then another and so on. Even the best-organised team meeting will reveal unexpected conflicts or opportunities that must be settled before further progress can be made on the original focal issue. During these excursions away from the original focal issue, each member must be flexible enough to move between roles as the focus changes in order to maintain progress of the team as a whole.
Leadership

Now we can consider the question of leadership abilities in relation to effective team-member abilities. Studies by Cowdroy in the architectural and engineering professions and related fields of industry and professions (using composite cross-cultural methods from psychology) [12] show that it is widely accepted that professionals (graduates) are expected to be leaders in the profession and industry, and the wider community, in relation to their qualifications and particular field of specialisation, experience and expertise. However these studies also distinguished between two types of leadership relevant to professional practice in engineering, each based on a particular form of authority: office-based leadership derived from authority or position or office held; and issue-based leadership derived from authority of a particular issue requiring a person with particular expertise to lead discussion or resolution.

Office-based leadership was shown to take three dominant forms:

Leadership from the front (assertive leadership) is associated with notions of leading by example, captains of industry and knights in shining armour; this is “I am in command; follow me” leadership and relegates all others to inferior status. However, leadership from the front depends on the others accepting and respecting the authority of their leader, and that depends on the perceived expertise of the leader in relation to the particular design issue being considered at any one time. All teams also need managing but the managing should be focused on facilitation of good team dynamics and optimal progress, and independent of any particular design discipline involved.

Leadership from behind which acknowledges the capacity of the group as a whole to achieve predetermined goals without further interference; this type of leadership is typically occupied with logistics support for the team and chairing meetings, but not with the proceedings of the team.

and leadership from within whereby the leader becomes part of the team and facilitates achievement of goals by contributing to team goal-setting and progress.

Issue-based leadership was shown to take only one form, that of leadership from within (as above), whereby an individual is expected to become the leader, and to facilitate achievement of goal setting and achievement, but only for the period of time during which that person’s expertise is most relevant to the technical issue being considered.

Leadership training introduced into some engineering courses is typically drawn from management training, and aimed at developing hierarchical assertiveness in business and/or in the community. This type of leadership is oriented towards office-based, hierarchical leadership, with particular focus on leadership from the front as described above [13]. While such leadership training is recommended by accreditation authorities in various countries, the abilities associated with this type of leadership have a very limited place in effective teamwork ability, which is essentially collaborative rather than hierarchical. On the other hand, the reverse applies: that is, development of effective teamwork abilities can contribute to subsequent development of leadership abilities.
The learning agenda

In the light of previous discussion, and in order to satisfy alignment requirements for QA, the learning agenda comprises:

- definition of explicit learning outcome objectives,
- development of curricula that directly address the learning outcome objectives,
- adoption of learning methods that directly address the curricula and the learning outcome objectives,
- and assessment protocols that directly address the curricula and the learning outcome objectives,

Learning outcome objectives

Also in order to satisfy alignment requirements, learning outcome objectives must be expressed in terms of development of ability to..... When this commitment is applied to abilities identified above as necessary for effective team membership, the learning outcome objectives can be defined as follows (in the same order):

- Development of ability to use multiple means of communication to convey ideas in a multidisciplinary design team/group environment;
- Development of ability to lead discussion in a multidisciplinary design team/group environment;
- Development of patience and persistence in conveying ideas to others, and in striving to understand what other members are trying to express in a multidisciplinary design team/group environment;
- Development of ability to follow (ie to accept the advice of other members) in a multidisciplinary design team/group environment;
- Development of ability to consider and generate alternative approaches in the interest of achieving consensus in a multidisciplinary design team/group environment;
- Development of ability to abstain (but maintain engagement with the team) when discussion is about matters that are outside the field of relevance of the particular member's area of expertise in a multidisciplinary design team/group environment;
- Development of ability (flexibility) to move freely between roles of leader, follower and abstainer in a multidisciplinary design team/group environment;

Curricula

The curricula must include both syllabus and learning protocols that directly address each and all of these seven learning outcome objectives. The syllabus can be derived directly from the seven learning outcome objectives discussed above. As previously argued, however, mere experience in learning groups is insufficient to develop the abilities identified in the seven outcome learning objectives identified above; students must also develop understanding of why each is necessary [14], and this requires learning of the rationale (theory and explanation) associated with each outcome learning objective and how each relates to team dynamics in industry (as presented in sections 2 and 3 above).
Development of ability therefore depends on development of both understanding (accumulation of knowledge) and ability to do (application of that knowledge) in each of the seven abilities indicated above. All seven learning objectives (abilities) must be met in order for a student to graduate, however there are various options for the timing of development of the respective abilities: they can be concentrated into a particular stage of the overall programme (eg, as a “foundation” ability in first year or a “finishing” ability in final year), or they can be progressively developed over several stages of the course.

Concentration in a particular stage implies that they will require intensive learning and assessment that will inhibit opportunity for integration with development of other abilities (eg, technical). Distribution over four or five years of the overall programme (ie, Teamwork 1, 2, etc as indicated in Table 1), however, will allow progressive and integral development of the student as a “complete professional”. Distribution over several years or stages also presents opportunity to introduce one or two of the learning outcome objectives at a time, and gradually integrate them with others introduced progressively until an integrated whole “teamwork ability” is achieved by graduation. The sequence of introduction of separate abilities is discretionary; a “soft” approach is to introduce the least challenging abilities first, and then move progressively to the more challenging abilities. Alternatively, the most essential abilities, ie development of ability to use multiple means of communication and development of ability to lead discussion might be introduced earliest in order for these abilities to be embedded and reinforced by repetitive application throughout the whole programme, and gradually integrated with the remaining abilities as each is introduced.

<table>
<thead>
<tr>
<th>Year/Stage</th>
<th>Essential technical abilities</th>
<th>Additional teamwork abilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Stage 4: All basic technical abilities (as required to satisfy accreditation)</td>
<td>Teamwork 4 (ability to lead in multidisciplinary team + flexibility to move between leader and follower)</td>
</tr>
<tr>
<td>3</td>
<td>Stage 3: basic technical abilities</td>
<td>Teamwork 3 (ability to abstain + patience/persistence)</td>
</tr>
<tr>
<td>2</td>
<td>Stage 2: basic technical abilities</td>
<td>Teamwork 2 (ability to follow advice of others + ability to consider/generate alternatives)</td>
</tr>
<tr>
<td>1</td>
<td>Stage 1: basic technical abilities</td>
<td>Teamwork 1 (eg ability to use multiple communication)</td>
</tr>
</tbody>
</table>

Table 1: Possible distribution of teamwork ability development across a four-year programme

A further opportunity is to consider teamwork abilities as “optional additional” abilities which, if undertaken and successfully achieved by the student, will contribute to achievement of higher overall grades, as indicated in Table 2. This approach is based on Transitional Criteria Assessment developed by Cowdroy [15], and reflects the reality of differences in professional achievement (or inclination) of practitioners in industry.
<table>
<thead>
<tr>
<th>Grade</th>
<th>Basic Content required for accreditation</th>
<th>Optional additional professional abilities achieved and demonstrated</th>
<th>Optional additional teamwork abilities achieved and demonstrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distinction</td>
<td>Basic technical abilities</td>
<td>Higher technical and professional abilities</td>
<td>Ability to lead in multidisciplinary team + flexibility to move between leader and follower</td>
</tr>
<tr>
<td>Credit</td>
<td>Basic technical abilities</td>
<td>Higher technical abilities</td>
<td>Ability to use multiple communication + ability to abstain + patience/persistence + ability to follow + ability to generate alternatives</td>
</tr>
<tr>
<td>Pass</td>
<td>Basic technical abilities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Notional TCA framework suggesting teamwork abilities as optional additional criteria for transition to higher grades

Learning protocols

Achieving the understanding component of the salient abilities can be considered as lower order learning tasks which can be achieved through didactic teaching in lectures, tutor-directed learning in group seminars, or self-directed learning from library or on-line resources. Achieving the application component, however, must be considered higher-order learning tasks, and the student must be able to apply gained knowledge through interaction in an actual group or team. The student must also receive evaluative feedback (from other members of the group or team and from faculty) on his or her success in applying the relevant knowledge and success in developing effective team member abilities. Group learning methods such as those characteristic of Problem-Based Learning and Project-Based Learning are ideal for this purpose, and allow the individuals’ group workabilities to be developed and progressively evaluated simultaneously with technical and other learning agenda.

Assessment protocols

In order to satisfy alignment principles, quality assurance requirements and student satisfaction expectations, achievement of each of the learning outcome objectives must be verified for each student. The assessment must also directly address learning achievement against each learning outcome objective. Assessment can be separate for each of the lower order and higher order learning components: the lower-order components (understanding, rationale and theory) can be analogue (eg, marks) assessment of set examination, essay or oral presentation, and the higher-order components (application) can be by competency-based assessment of demonstrated performance.

Alternatively, these two methods of assessment can be undertaken simultaneously, with the student presenting (demonstrating) performance in a real group environment, and then presenting an oral self-evaluation of his or her performance, based on the theoretical components of the abilities set out in the curriculum. Assessment by faculty is then of the level between actual observed performance and what the student presented in the evaluation. The group environment in which this assessment is conducted can be in a group specially contrived for the purpose, or in a group undertaking other problem-
solving tasks. That is, assessment of group-work ability achievement can be undertaken without adding to the student or teacher/tutor workload.

Adoption of any one or more of these various assessment protocols is discretionary, and all can be accommodated within the two curriculum frameworks indicated in Tables 1 and 2.

A significant obstacle to individual assessment in group and team environments has been lack of definition of individual attributes that contribute to affective group/team performance, and lack of verifiable criteria for measurement of those attributes in individuals [16]. Absence of verifiable criteria, combined with student dissatisfaction about group assessment has resulted in many attempts to incorporate group problem-solving being abandoned because it is “too hard”, with the result that this crucial aspect of relevance to professional practice and career development is also abandoned.

Each of the individual professional abilities required for effective team performance outlined above can be (and must be) translated into learning goals, curriculum frameworks and assessment criteria. It is not the purpose of this paper to discuss curriculum frameworks or learning methods, but such discussion would inevitably gravitate towards a mix of brief on-line notes to explain each of the seven abilities, how they are to be engaged and how they are to be assessed, and practical group assignments that would allow students to learn by participating and critically considering their own and others’ performance on each of the seven abilities. Further it would lean towards the practical group assignments being within the present technical learning programme. That is, no separate or additional group assignments need be undertaken; teamwork abilities can be observed and assessed in parallel with observation and assessment of other (eg technical) abilities.

The Transitional Criteria Assessment (TCA) framework allows for simultaneous assessment at all levels from bare minimum technical pass level (eg 50%) through to “brilliant” level associated with outstanding students in each stage of a course. The TCA framework allows all students to be assessed fairly and transparently regardless of differing abilities, performance and achievements by requiring all students to satisfy minimum accreditation requirements in order to achieve a pass grade, with the option of passing additional layers of assessment criteria (typically additional professional skills) in order to “transit” to higher grades. Assessment of individual teamwork abilities is readily accommodated in the TCA framework by including some or all of these within the minimum pass-grade criteria, or within the “additional abilities” options for transition to higher grades as indicated in Table 1. Alternatively, development of teamwork abilities can be mandatory and progressive, eg by distribution across a programme as suggested in Table 2.

**Conclusion**

Development of teamwork abilities has been identified as an imperative part of engineering education, due to governments' Innovative Society policies and initiatives, and due to the importance of team design to innovative and complex engineering projects.
throughout industry. Group work has been increasingly adopted into engineering education, however this has been problematic, due primarily to customary “one size fits all” group assessment practices that obscure individual achievement, flout QA requirements of alignment, and cause the student dissatisfaction that is the main cause of the “problems”.

This paper has drawn directly on attributes expected of practitioner engineers engaged in design teams, derived from several lines of intensive research into the dynamics of design teams working on highly innovative projects in industry. Seven salient attributes were identified in that research, and those seven have been translated into seven outcome learning objectives. Curricula that align with these objectives have been presented, together with suggested learning methods and assessment protocols that are also in specific alignment. Discretionary alternatives have also been suggested so that the rationale presented in the paper is not dependent on any particular teaching/learning approach or assessment method.

The outcome learning objectives, learning methods and assessment protocols described in the paper have been employed with great success in engineering and related disciplines in higher education. These reforms have overcome the “problems” with group work and, together with other initiatives to achieve alignment, they have been particularly successful in overcoming student dissatisfaction, improving student morale and motivation, and achieving outstanding accreditation and quality assurance ratings.

References


[16] Biggs, J. (2003) op.cit

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Understanding Feedback in an Authentic, Ill-Structured Project through Discourse Analysis: Interaction between Student and Instructor Objectives

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Abstract: This paper presents a case study of feedback in an authentic engineering project in which the primary objectives of the students and the instructor are different but complementary. Students focus on completion of the authentic task. The instructors’ intent is to promote knowledge integration of core engineering science concepts. These perspectives are bridged by the project’s authentic, situated context. Using an episodes framework to examine a feedback session, we investigate how the student objectives, the instructor objectives, and project contextualization are addressed and how these three elements interact. They are found to be interwoven generally initiating with student objective focused discussion, incorporating instructor objectives, as appropriate, as tools to help students achieve their objectives. Project contextualization reinforces the authenticity and contributes to validating the utility of core content and concepts.

Context

Feedback has been shown to be one of the most important tools used by instructors to help students close the gap between actual and desired performance. According to a meta-analysis by Hattie and Timperely (2007) the effect size of feedback is among the highest of all educational factors, weighted heavier than such factors as students’ prior cognitive ability, socioeconomic status, and reduction in class size. While feedback has been shown to strongly influence student performance and learning, explicit research on the effect of feedback in engineering education is sparse. Findings from studies of first-year engineering students (Bjorklund, Parente, & Sathianathan, 2002; Moreno, Reisslein, & Ozogul, 2009) show that feedback is positively related to learning gains. These results are consistent with studies in other disciplines (Kuh & Hu, 2001). However, there is no general agreement on what characterizes “effective” feedback. Additionally authentic, situated environments are believed to benefit student learning. Studies of feedback in authentic projects are uncommon and needed. This study extends our group’s use of episodes as a discourse analysis framework to investigate feedback in the industrially situated Virtual Chemical Vapor Deposition (CVD) Laboratory Project.

Over the last seven years, we have developed, implemented, and been assessing the authentic, industrially situated Virtual CVD Laboratory Project (Koretsky, Amatore, Barnes, & Kimura, 2008). This project provides opportunities for student teams to develop and refine solutions to an authentic engineering task through experimentation, analysis, and iteration. While the phrase “student objectives” can be interpreted in many ways, in this study the student objectives encompass the explicit project objectives: develop an
optimal ‘recipe’ for industrially-sized, Chemical Vapor Deposition (CVD) reactors which deposit thin films on polished silicon wafers, maximize utilization of the expensive and hazardous reactant (referred to as DCS), and minimize the development and manufacturing costs. To achieve these objectives, student teams must find suitable reactor input variable values (temperatures along the reactor, flow rates for two reactants, pressure, and reaction time) that result in films of uniform thickness at the desired target value. The instructor’s learning objectives focus on professional development skills (e.g., working in teams, communication) and integration of core engineering science concepts (e.g., material balances, reaction kinetics, statistics).

A typical student team devotes a substantial 15 - 25 hours to this complex, three-week project. A summary of key project milestones and corresponding opportunities for feedback is shown in Table 1. The feedback analysed in this paper occurs during the initial coaching session, shaded in blue. In this 20-30-minute meeting, students must deliver to the coach a memorandum that specifies the values for their first run variables, a strategy for subsequent runs and experimental data evaluation, and a budget (in virtual dollars) for the entire project. This assignment places an unusual responsibility on the students, requiring them to formulate and solve a problem that requires integration of prior knowledge from previous courses. In the initial coaching session, the coach acts as a mentor or boss would in industry. The coach asks questions to guide the students in further developing their strategy, initial variable values, and budget. Feedback is carefully tailored to engage students in identifying gaps in their current design and directing attention to methods for addressing those gaps.

Table 1: Timeline and opportunities for feedback in the Virtual CVD Laboratory Project.

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Key Project Milestones</th>
<th>Student-Coach Opportunity for Feedback</th>
</tr>
</thead>
</table>
| Project Begins | • Goals of the task are introduced  
• Criteria for success are indicated  
• Provided with laboratory notebook | Instructor (coach) delivers introductory presentation on integrated circuit manufacturing, some engineering science background, the Virtual CVD software interface. Also presented are project objectives and deliverables. Feedback is limited to questions and in-class interaction. |
| End of Week 1 | • Initial coaching session 
○ Variable values for first run  
○ Experimental strategy | Feedback takes the form of a 20-minute coaching session in which coach and students ask questions and discuss the students’ design strategy and initial variable values. If initial variable values and strategy are acceptable, they are granted access the Virtual CVD laboratory. |
| End of Week 2 | • Update coaching session  
○ Progress to date | Another opportunity for feedback is this second meeting between student teams and coach. Discussion includes progress to date, issues students may have, and the direction they are going. |
| End of Week 3 | • Final Recipe  
• Final Report  
• Final Oral Presentation  
• Laboratory Notebook | Teams deliver a 10-15 min oral presentation to the coach, two other instructors, and the other students, followed by a 10-15 minute question and answer session that affords additional feedback. Final project feedback consists of grades and written comments on final deliverables. |

Research Questions

Using the episodes framework, what evidence is there that the semi-structured feedback sessions in the Virtual CVD Laboratory Project address the: student perspective of task completion, instructor intent of knowledge integration, and authentic, industrial context of the project? Ultimately, we are interested in understanding how these elements interact with one another to contribute to student learning.
Theoretical Framework

Hattie and Timperley (2007) describe feedback as a process in which instructors make learning objectives clear to students, assist students in ascertaining where they are relative to those objectives, and then help students move their progress forward. Researchers have advocated that feedback works best when it directs student attention to appropriate goals and actions (Kluger & DeNisi, 1996), or encourages student reflection (Bangert-Drowns, Kulik, & Morgan, 1991). Research also suggests that appropriate feedback is specific to the learning context of the student and/or task (Shute, 2008). Prince and Felder (2006) discuss the trade-off between directive projects, which can be crafted to specifically address learning objectives, and ill-structured projects that require students to formulate the project and develop appropriate strategies. Ill-structured projects are generally more authentic and have been shown to increase student motivation; however, it is more difficult to guarantee that specific learning objectives, or what we term "instructor objectives," are met.

We propose that authentic projects motivate students and allow them to integrate prior knowledge in part because the student objectives can differ from the instructor objectives. We wish to study these contrasting, but complementary, perspectives in the Virtual CVD Laboratory Project. The intent of feedback in this project is to help students close the gap between their present performance and the desired performance; however, it takes a slightly different form than described by Hattie and Timperley. The instructors make student objectives explicit, and then through feedback assist students in integrating and then addressing the instructor objectives. We posit that this relationship between student objectives and instructor objectives is present in many project-based learning experiences and that intentioned feedback based on these juxtaposing objectives can be more effective in helping students close the performance gap. This study forms a foundation to explore this conjecture.

We use the analytical framework of episodes to examine the feedback. This framework has been used for discourse analysis in several fields such as linguistics (Korolija & Linell, 2011) and medicine (Cordella, 2004). Our definition of the episodes framework is described in more detail elsewhere (Gilbuena, Sherrett, & Koretsky, 2011) and is partly adapted from van Dijk (1981): each episode addresses a specific topic, labelled the episode 'theme;' each episode has a clear beginning and ending point; and each episode has a sub-structure that includes up to four 'stages.' Smaller episodes may also be nested within larger episodes, as illustrated in the Findings & Conclusions section of this paper.

Our episode stages include: Surveying, Probing, Guiding, and Confirmation. In the Surveying stage, the coach assesses the student team's current understanding by reading their memorandum, asking broad questions, or listening to students explain their strategy; the coach attempts to identify potential problem areas in the team's core knowledge or design strategy. Identification of a potential issue initiates the Probing stage where the coach asks probing questions in order to assess if there is indeed a problem. The Guiding stage, where the coach attempts to guide the team toward a more favourable approach or a deeper understanding, occurs if the coach assesses that a problem is present; this stage
may include leading questions. Finally, in the Confirmation stage confirming statements such as “ok” and “alright” (often by both coach and students) conclude the episode. Episodes must contain at least two stages. The stages, while central to our episodes framework, are not the focus of this investigation.

**Methods**

This paper presents a case study of one team, a subset of a larger investigation of student learning in virtual laboratories. The undergraduate students were in the 4th or 5th year of a chemical, biological or environmental engineering program and enrolled in a capstone laboratory course of approximately 80 total students. The team, of two female students and one male student, was self-selected and maintained for the entire course. Team selection criteria for this research are described elsewhere (Gilbuena, Sherrett, & Koretsky, 2011). One faculty member, the coach, participated in this study and has coached over 60 teams in the same capstone course over several years. The faculty member also has many years of thin films processing experience and has developed several courses on the subject.

The primary data source for this study uses the think aloud protocol, and is comprised of audio recordings of the team as they “think aloud” while completing the project. Transcripts of the audio recordings were analysed. For this study, we focus on the initial coaching session transcript. Two researchers examined the transcript to investigate the connection between student and instructor objectives by coding the coaching session transcript; each researcher coded the transcript individually by identifying episodes within the transcript and labelling the key theme of each episode. After coding, the researchers compared the coded transcript; major episode topics were agreed upon almost unanimously and discrepancies were easily resolved. Episode themes were categorized as follows:

1. **Student Objectives** - *Inputs variables and performance metrics* focuses on one of the reactor input parameters (reactor temperature, pressure, or input flow rates) or one of the project performance metrics (wafer uniformity, gas utilization, or project budget).

2. **Instructor Objectives** - *Core content and concepts* refers to topics from previous courses (e.g., material balance, reaction kinetics, statistics, project management, writing).

3. **Project contextualization** emphasizes the authentic context of the project which situates it in industrial practice. For example, an episode in this category might contain discussion of the typical discussion between engineers with operators in a processing facility.

Themes in the second category were member checked with the coach. A graphical representation of coaching session episodes’ length and chronological order was prepared based on this categorization.
Findings & Conclusions

For the team studied, the coaching session contained twenty-five distinct episodes; nine addressed student objectives of inputs and performance metrics, thirteen attended to instructor objectives of core content and concepts, and two provided project contextualization. Figure 1 shows the chronological order of episodes within the coaching session. The 20-minute coaching session consisted of approximately 2200 words and the length of the box representing each episode is scaled to the word count. Inputs and performance metrics episodes are denoted with a white box, core content and concepts episodes are shown as a box with a grid pattern and project contextualization episodes are denoted with a shaded box. Each episode is labelled with its particular theme.

![Diagram of coaching session episodes](image)

Figure 1: Chronological representation of episodes in a coaching session.

Figure 1 illustrates the approximate proportion of discourse allotted to each of the discussion themes. The themes discussed here are similar to those reported for other
teams (Gilbuena, Sherrett, & Koretsky, 2011). The pattern of discussion begins to illuminate the interaction between student objectives and instructor objectives. Throughout the coaching session we see smaller episodes relating to instructor objectives nested within the context of larger episodes relating to student objectives. For example if we look at the second row of discourse in Figure 1, discussions of diffusion and reaction kinetics are nested within the larger context of pressure. The students must select a value for pressure in order to proceed with their experiments; the discussion initiates specifically addressing this need. The instructor then connects the core concepts of diffusion and reaction kinetics as a way for the student team to think about their objective. We next unpack this interaction.

The pressure episode begins after the temperature and sources episodes conclude; the coach starts by directly asking the students how they determined the starting variable value for pressure. They respond citing a literature reference, and state that they didn’t think the pressure was as important as the other variables. The transition from strictly focusing on the input parameter of pressure, a student objective, to diffusion as a focus is illustrated in the following excerpt. It occurs with a question posed by the coach regarding what affects pressure and the team's answer of 'diffusion:

Coach: So what do you think affects pressure?

Student: Diffusion

Coach: So pressure is diffusion. In terms of diffusion where do you want the pressure to be?

They discuss the core concept of diffusion, an instructor objective, for 275 words within the context of its impact on the student objective, pressure. With probing, it appears the team has a misunderstanding about the role of diffusion and the impact of pressure on the performance metrics. The team is guided to conclude that diffusion is not the only way pressure affects their performance objectives. A discussion of the concept of reaction kinetics, another instructor objective, follows. The students are guided to relate pressure to concentration and recognize its impact on reaction kinetics. The transcript excerpt below shows the transition beginning with revisiting a previous question; the coach asks what other thoughts the students have about why the pressure should not be set too low. Students respond relating pressure loosely to reaction rate, after which the coach guides the students with a leading question that focuses discussion on the contribution of pressure to reaction rates.

Coach: Any other thoughts?

S1: That makes it, basically you are limiting, the thing that's limiting what's happening would be how they hit and so you'd have to model basically the reaction rate based on how they hit instead of

Coach: You talked about reaction rates, what are reaction rates a function...

S1: Temperature
Coach: Temperature, what else?

S1: Concentration

Coach: Concentration, so what happens to concentration as pressure goes down?

S3: Concentration goes down

Coach: Concentration goes down

S3: If the pressure goes down too much it will limit how concentrated

S1: And the reaction rate goes down, concentration goes down

The students then recognize that pressure determines the concentration which in turn impacts the reaction rate; this illustrates the strong link between a student objective (what value will we pick?) and the instructor objective (integrating the concept of reaction kinetics into this authentic task). An example of project contextualization is illustrated at the conclusion of the reaction kinetics episode with a small episode focused on situating the project in the industrial context, shown below. This situating episode links the concept of reaction kinetics to its impact on high-volume manufacturing.

Coach: Alright, and what's the problem with that in high volume manufacturing facilities?

S1: You have waste

S3: You can't get things done very fast

Coach: You can't get things done very fast and so you

S1: Okay

S3: It will still get deposited or it will still get there, it will take a lot longer and it's not

Coach: You're making less product than your competitor.

S3: It might be uniform, you might have high utilization but oh we take 4 hours. Wait 4 hours? Why are you taking 4 hours?

The last row illustrated in Figure 1 represents approximately the final quarter of discourse and consists of the meeting wrap-up discussion. During this time, students may ask final questions regarding aspects they are unclear about. In addition, many topics previously explored in depth are touched upon as a reminder of what aspects of the student's design strategy merit attention. During this portion of the meeting, for example, pressure is revisited in a student initiated discussion where one student asks the coach if there is more to consider with pressure and another student responds that their pressure is fine. The coach leaves that input variable for the students to explore, without adding additional insight.
In conclusion, the three theme categories are interwoven as the students and instructor discuss the experimental design strategy of the team. Episodes in the core content and concepts and project contextualization categories were found to be nested within episodes in the inputs and performance metrics category. This feedback, perceived as effective by students (Gilbuena, Sherrett, & Koretsky, 2011; Koretsky, Kelly, & Gummer, 2011), starts primarily focused on student objectives of inputs and performance metrics. Core content and concepts are tools incorporated, as appropriate, to help students understand and achieve their objectives. Project contextualization validates the utility of core content and concepts and increases student motivation through the reinforced authenticity of the project.

**Recommendations & Future Research Plans**

More intentioned research investigating feedback in engineering education is needed. Of particular interest are the investigations of feedback in authentic projects and projects in which the student objectives differ from the instructor objectives. We propose that the episodes framework may be used to explore a variety of projects, characterize the nature of feedback, and examine the extent to which each participant's objectives are being addressed.

We plan to extend this investigation to include five additional student teams from three cohorts, to further explore the presented findings. Episode stages analysis is also planned to provide additional information as to the nature of feedback in these coaching sessions. To establish the effectiveness of feedback present in coaching sessions, we plan to analyze think aloud transcripts from team meetings that occurred before and after the coaching session. Analysis of pre coaching session transcripts is expected to provide indications of the team's understanding of content and concepts before feedback was provided; the analysis of post coaching session transcripts is expected to provide evidence of the impact of the feedback given in the coaching session on later discourse and actions of the team.

**References**


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Topic: Tools 2 – Chair: James Pellegrino

Quality of experience of online learning tools

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Abstract: Online learning tools have become important components of teaching and course delivery. This paper discusses the issues surrounding research into Quality of Experience (QoE) for online learning tools and how it relates to technical performance, Quality of Service (QoS). The relationship between QoE and QoS for online learning tools is often considered important for describing the optimal conditions for online learning environments. Such research largely ignores the vital issue of how learners differ from consumers in their use of information and communication technologies such as interactive multimedia environments. The implication of this difference for understanding technology use for learning is presented and the need for an empirical study to address this is argued for. A pilot was undertaken to further define the methodological requirements of conducting a study into the impact of system performance on QoE. The findings of the pilot study describe issues and implications for designing a research methodology which can begin the process of mapping the QoE to QoS relationship for online learning.

Introduction

Online learning activities are widely advocated as tools to enhance student engagement and assist their learning journey (e.g., Herrington, Oliver, & Reeves, 2003). In particular, modern distance education uses Information and Communication Technology (ICT) in an attempt to provide students with equitable learning experiences in online environments, when proximal learning is not available. Learning aids span a variety of applications from lecture recordings to remote access technologies. Remote Access Laboratories (RAL), for example, widely discussed in engineering disciplines, allow students to use software and hardware remotely (e.g., Kist & Gibbings, 2010). As online learning systems use telecommunication infrastructure and the Internet, system performance depends on access speed, geographical location as well as network conditions, e.g. traffic.

There has been much work in telecommunications research on capturing the performance of applications that rely on networks from a technical as well as from a consumer perspective. The former are identified by the term Quantity of Service (QoS), the latter by the term Quality of Experience (QoE). "QoS is defined as the ability of the network to provide a service at an assured service level" (Soldani, Li, & Cuny, 2006). Technical performance parameters that relate to QoS, such as delay, jitter and throughput, are relatively easy to measure; however, they say little about the experience of a user or if the system was fit for a purpose.
The term QoE as it is frequently used in a technical context “refer(s) to the overall acceptability of an application or service, as perceived subjectively by the end user” (Kuipers, Kooij, De Vleeschauwer, & Brunnström, 2010); “how satisfied he or she is with a service in terms of, for example, usability, accessibility, retainability and integrity of the service.” (Soldani, et al., 2006); or “as the basic character or nature of direct personal participation or observation” (Kilkki, 2008). However, no QoE definition is universally accepted or widely used. The term is also well established in psychology and other disciplines (e.g., Harman 1990) where it has a more general meaning. In the context of this project, the most suitable definition is based on Brooks and Hestnes (2010) and extended by linking experience to a task, i.e. “QoE is a measure of user performance based on objective and subjective psychological measures using a service or product”[p12] to achieve a particular task or objective.

QoE of students in learning environments, however, does not directly fit this definition as it implies the quality of a learning experience. Overall, this study investigates quality requirements to achieve good learning outcomes for distance students using online learning systems in the broadest terms. A key focus of the research project is the highly interactive Remote Access Laboratory. This paper focuses on the effects of system performance on the Quality of Experience of learners. The remainder of this paper introduces context and related work, theoretical framework and the pilot study. Implications for the main study and future work conclude the discussions.

**Context – QoS, QoE and Quality of Learning Experience**

Much of the attention to Quality of Service for online learning environments derives from related studies of QoS in telecommunications or other consumer-based Interactive Multimedia Environments (IMEs). As such, most of the literature which attempts to account for the effect of QoS on QoE in learning is geared towards the users of technology as consumers, with well defined and well understood needs and expectations (including Moller, Engelbrecht, Kunhel, Wechsund, Weiss (2009) and others). Where multimedia environments are consumer driven, decades of market driven research into consumer uptake and acceptance of ICTs provides both explicit and cumulative understandings of what users expect, and how they behave and how they perceive the technology that they are “consuming.”

In attempting to adapt such a body of knowledge to understanding the use of technology in learning environments, where users are learners, relevant dimensions affecting Quality of Experience may not be the same. Operating as if they were is an assumption that requires testing. For example, technology use should be expected to be different for learning in terms of users” motivation, their purpose in completing tasks, as well as the nature of the tasks themselves. Each of these variables has the potential to significantly influence user behavior and perception, and, thus, the nature of quality of experience. In evaluating the effect of quality of service on quality of experience of online tools for learning, it is therefore necessary to gather data which has the capacity to reveal how system performance issues have affected the learner in the process of carrying out their
tasks. In other words, this involves measuring if QoS issues have affected the learning and what the effect has been.

Wu et al. (2009) make a significant step in this direction with a shift of focus from a system-centric view of interactive multimedia environments to a human-centric one, encompassing theoretical frameworks from psychology, cognitive sciences and sociology as well as information technology. They attempt to “map the QoS-QoE relationship” by “capturing the human-centric quality modalities.” (p. 481). In doing so, they define quality of experience as “a multi-dimensional construct of perceptions and behaviours of a user, which represents his/her emotional, cognitive, and behavioural responses, both subjective and objective, while using [an IME] system” (Wu et al, 2009, p. 483). Their model maps the relationships among various QoS and QoE factors.

Despite this step forward, this model does not take a specific focus on tasks or learning environments. It is known from the wide range of available literature on online learning that there are many course design, learning tool design and pedagogical factors which have a significant influence on the way that learning takes place in online environments (Mayer, 2003). Sambrook’s (2001) in-depth study demonstrated that many factors, such as user-friendliness, presentation, structure of tasks and navigation within tasks, all affect the quality of online learning tools. These are design and pedagogical issues which determine how the learner experiences the online environment. At an even more basic level, ubiquitous in much educational literature is the basic premise that things like a clear set of instructional goals, the perceived relevance of tasks in relation to these goals and the resultant motivation and cognitive processes of learners, are all fundamental to how learners behave and perform (Killen, 2007, Department of Education, 2002). In this respect, there are factors relevant for learners using interactive multimedia environments that are not common to more general consumers of IMEs.

In attempting to deal with such issues, Moebs” (2008)” work focussed on the effect of “flow” (defined as complete immersion within a task, leading to intensive interaction within an activity) on QoE for learners, flow being directly affected by QoS issues such as access speed and consistency. Her detailed QoE model included many factors present in the learning environment which can mediate the relationship between QoE and system performance. These factors include “choice of learning path, learning styles, feedback, interaction” and “clear sets of goals”. Despite this, her quantitative method of measuring the effect of flow on QoE did not account for these factors, and consequently, the model is not capable of explaining the relationships among all of the elements that are presented.

Whilst the qualitative tool used in Moeb”s study purported to investigate “how important to flow [these pedagogical] factors are,” this was done using a Delphi panel of technical experts, rather than an instrument which captures data from the learners or learning environment, or even educational or pedagogical experts. As such, her study does not account for the relative effect of all the factors that are expected to impact on QoE for learning. Although flow is expected to be highly relevant to the effect of system performance (QoS) on QoE, until it is understood how this is mediated by other factors and the ultimate performance of learning tasks, the picture of the QoS to QoE relationship is incomplete.
Theoretical Framework – Dimensions of QoE and their Effect

The present study attempts to address the gap in the current body of work with a mixed-method approach to capturing data about learning from the learning environment itself. It will attempt to answer the question "What dimensions of quality of experience (QoE) of online learning can be affected by QoS, and how?" Ultimately, ten participants will be used in a case study which attempts to map the relationship between QoE and QoS for their online learning environments. It is expected that this case study will have the potential to provide the basis for future research in which the emergent model can be tested for reliability and relevance across various contexts.

Figure 1 depicts the framework that is proposed as a basis for evaluation of the above research question. It is based on the work of (Mayer, 1989) which proposes the overall cycle and components of the teaching and learning process, and Gilbert, Moreton and Rowley (2007), who demonstrated that aspects of technical performance of online tools can impact on students’ perception of quality of online learning. By investigating each of these components together, a theoretical map of the relationship between QoS and QoE, including the effect of the mediating factors between them, can be proposed. This study will test this construct via student surveys and focus groups; as well as providing a more detailed view of the components presented.

Methodology – The Pilot Instrument

A pilot study was conducted in order to explore the relevant factors discussed above, and to further define the requisite methodology for the main study. Whist it did not have the capacity in itself to demonstrate the relationships proposed in Figure 1, it was intended as a means of further defining the data needed in the main study in order to be able to do so. The pilot took the form of a focus group and survey of students, asking about their experiences with online learning in a particular course, and any issues (technical or otherwise) which they may have experienced.

Table 2 describes the dimensions and factors that are relevant to quality in learning environments as described by the work of Sambrook (2001). This comprehensive description of the learning environment formed the basis of the range of questions in the survey, so that the instrument would have the capacity to capture data about any or all of
these relevant dimensions. This was especially important given that the factors affecting quality of experience for learners in particular are not known.

In combination with conducting this survey, a focus group session was carried out with the same student participants, in order to explore their answers to the survey, and how the survey instrument itself was understood. The constant comparative method was used to analyse the focus group transcripts.

Table 1: Factors comprising the relevant aspects determining success in online learning according to Sambrook (2001)

<table>
<thead>
<tr>
<th>Learner Characteristics</th>
<th>Instructional Objectives</th>
<th>Task Processes/ Instructional Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience online, with ICTs and with online learning tools</td>
<td>The link between the theory and application of what is being learned</td>
<td>The learning path (sequence, e.g. open or linear)</td>
</tr>
<tr>
<td>Demographics (age, gender, location, access to quality internet connection)</td>
<td>The currency of materials and their application</td>
<td>Task requirements (e.g. processes to be performed)</td>
</tr>
<tr>
<td>Attitudes to the course and learning in general</td>
<td>The relevance and coherence of materials and tools and their application</td>
<td>Access to and usability of tools required for task completion</td>
</tr>
<tr>
<td>Prior experience and capacity with learning in the relevant subject area</td>
<td>The objectives of specific tasks</td>
<td>The ease of interpretation of task requirements</td>
</tr>
</tbody>
</table>

Findings – Implications for the Main Study

The pilot raised a number of empirical issues for the main study. First, it became clear that a common understanding of what constitutes a “tool for learning” cannot be assumed, and, therefore, the main study has to take a targeted focus on specific activities within the online learning environment to ensure validity. Participating students indicated that they tended to view learning as the acquisition and mastery of content knowledge and therefore saw learning activities as those tasks which were involved with achieving this. This significantly reduced the number of “tools” which they saw as being central to learning in the course they were participating in. It also influenced how they perceived the function of ICTs which were available to them in the course of their learning.

ICT tools such as the discussion forums for the course and the course web page in general were seen as having an administrative function only, rather than one of supporting and promoting the learning itself. It can be assumed that this results, at least partly, from the design of the course in which they were participating – the focus of which was content acquisition, rather than, for example, the application of theory to practice. However, this raises an implication which is independent of course context: Which online learning tools learner perceives as significant for their experience may depend largely on how they understand the function of the tool that they are using. If the relevant tool is not perceived as being central to the learning task, the role of the user in cannot be understood as purely that of a learner. This is a potential confound in describing the QoS to QoE relationship for learning.

This finding strongly suggests that the selection of a specific, central and relevant tool would yield the most significant data in the main study for answering the current research question. The clearest opportunity for this is in evaluating the use of a Remote Access Lab.
tool in which students conduct specific activities that are explicitly central to their learning. This RAL tool is sufficiently sophisticated to be understood by the students as a tool for learning, rather than just an administrative aid. Students see the link between experiment and theory.

It requires learners to perform more complicated learning processes than simple memorization of content, such as the application of theoretical concepts to instances of practice. As such, participants using this tool can be expected to more clearly understand the centrality of the tool to the learning task. This should act to avoid the potential confound that was raised by the pilot study. Further, the use of the RAL tool by learners is more likely to be susceptible to discernable quality of service issues such as speed or consistency of access, than ubiquitous tools such as forums or podcasts, creating a clearer picture of the impact on QoE. The second implication that arose from the pilot derived from the fact that the participants chose to focus mainly on course design and delivery factors when speaking about issues that were significant for their learning. They did not have many significant issues to report that could be said to derive from the quality of service of their online tools. Whilst the pilot did not have the capacity to reveal the reasons behind this, this does highlight a fundamental question for the main study to explore: Can the effect of quality of service issues be sufficiently isolated from educational design considerations to understand the effect of QoS on quality of experience? It is possible that quality of service may not emerge as a significant determinant of the perceived quality of learning experiences compared to other factors in the learning environment.

**Future Work – The Main Study**

Participants in the main study will be situated in a variety of locations expected to produce a variety of QoS parameters. Each participant will be sent an inline network traffic monitor to capture quantitative data about the quality of service of their online learning tools in discrete learning sessions. These parameters include access bandwidth (“speed”) of the Internet access; Round Trip Time (RRT) to the university server (“delay”) determined by the geographical location and Internet service provider; consistency of service; as well as network traffic information for the duration of the experiment. The learning sessions that are monitored will form part of participants’ normal course work. As such, the learning activities being studied will be sufficiently contextualised and relevant to the students to ensure theoretical validity. The inline traffic monitor will have no impact on the learning itself, as it will not intrude on the learner’s perception of the learning environment.

After completing monitored sessions, participants will also fill in a log of any issues they encounter. This will capture their perspectives on what any issues were, their cause, how they affected the learning, and what the student did in order to deal with them. This data will be compared to the network traffic data to uncover patterns between technical performance and learner behaviours and perspectives. It is expected that the data will reveal whether there are any consistent patterns linking QoS to QoE, as well as the effect on and of other mediating factors that are present in the learning environment. The use of these instruments together has the potential to isolate which performance issues were significant in what ways and what their impact was for learning. For example, there may
be a close correlation between system events and learner reported issues, or a significant
divergence. Either of these outcome has can generate significant findings about the
research question, as either scenario can give a strong indication of the importance of QoS
in online learning environments.

In line with best practice in diary studies (Bernard, 2006), students who have kept logs
will be asked to do a telephone debrief to clarify the data they have recorded. This will
allow the researchers to follow up on and triangulate the data from the first two
instruments. For example, if there is an event reported in the log instrument which raises
questions when compared to the monitor data, this can be investigated by asking targeted
questions about the event. Furthermore, the significance of the events for the participants
can be clarified. This adds validity to the methodology employed. Even as a case study, the
methodological framework being employed demonstrates sound theoretical validity (Yin,
2009), by allowing for all of the factors that impact on quality of experience in learning to
be captured in the data.

Conclusion

This paper discussed the outcomes of a pilot study that explores relevant factor that
impact on the performance of online learning systems. Key outcomes of this investigation
include that students do not necessarily identify learning tools as such and this might
impact on their quality perception. The development of the research methodology and
analysis of the pilot study have highlighted some significant issues for the field of research
which the main study will attempt to pursue and address. The main study will be
undertaken in the second half of 2011. Until the significance of quality of service for online
learning environments is explored, it is unknown how the existing literature on quality of
service can inform the design of effective online learning environments. It is vital that the
above issues be explored and understood if further research into quality of service for
online learning is to be fruitful. Results will remain relevant as the use of multimedia and
other learning technologies will continue to increase in the foreseeable future.

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objective and quantitative is important. Network, IEEE, 24(2), 8-13.


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Concept inventories as aids for instruction: a validity framework with examples of application

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Abstract: The utility of concept inventories (CIs) as assessment tools in engineering education settings is considered in the context of contemporary theories of assessment design, measurement, and validity. A comprehensive approach to validity analysis is described and applied to available evidence for three STEM CIs – CATS, TTCI, & SCI. The results reveal that a systematic approach to the compilation of validity evidence can enhance the design, evaluation, interpretation, and diagnostic application of CIs as well as their use in engineering courses as aids to assessment and instructional practice.

Study Background

The overarching goal of this project is to implement a comprehensive, multidisciplinary approach to the design and validation of concept inventories (CIs) that transforms how they can be used in STEM classrooms and enhances their instructional effectiveness and impact on student learning. We are conducting a validity analysis of three specific concept inventories used in engineering education: (1) the Thermal and Transport Concept Inventory (TTCI) (Miller et al., 2005; Miller et al., 2006), (2) the Concept Assessment Tool for Statics (CATS) (Steif & Dantzler, 2004), and (3) the Statistics Concept Inventory (SCI) (Allen et al., 2004). The approach we are taking is designed to generalize to other CIs. The current work takes full advantage of, and builds upon, prior conceptual and empirical work in developing the TTCI, CATS and SCI. We intend to demonstrate the general and specific benefits derived from applying a multifaceted validity analysis model to a range of concept inventories.

Research Questions

Instructors in engineering programs regularly raise concerns about the problems their students have in developing deep conceptual understanding within particular engineering disciplines and the challenges instructors face in assessing such understanding. Broad coverage of established sets of topics as commonly taught in engineering courses and a focus on developing practical problem solving skill too often results in students able to pass course exams without achieving deep conceptual understanding within the discipline. Concept inventories have been touted as one solution to this instructional and assessment dilemma. Examination of the validity and utility of CIs is especially important given their increased deployment in engineering courses as tools for both student and instructional evaluation.
We are conducting a rigorous examination of the extent to which CIs “measure up” to the claims made about them as assessment tools and an examination of the ways they can be useful to engineering educators. The project’s research program is driven by a validity analysis framework (outlined below) focused on three broad research questions. What does a given CI really measure relative to its conceptual foundations and the intended measurement constructs? Do questions and multiple choice distractors in CIs support diagnostic methods to reliably identify desired conceptual understandings as well as robust misconceptions (e.g., “heat and temperature are equivalent”)? How should instructors think about incorporating CIs into their instructional practice and does adding diagnostic measurement and reporting lead to formative use of CIs in classrooms and improved student learning?

Theoretical Framework

The STEM area CIs under study provide good examples of the use of conceptual models of understanding in instructional domains to systematically generate sets of test questions. The resulting student performance data have the potential for rigorous interpretation relative to a cognitive model of domain understanding. When such an assessment is designed and then validated, the information about student understanding and performance that it generates should be useable for changing the conditions of instruction and the nature of student learning outcomes. Successful change, however, depends on: (1) developing methods for extracting relevant diagnostic information in a timely and rigorous manner, and (2) validating the instrument relative to its intended purposes and uses.

Our framing of the validity analysis challenge with CIs is based on the “assessment as reasoning from evidence” framework articulated in the National Research Council report Knowing What Students Know: The Science and Design of Educational Assessment (Pellegrino, Chudowsky & Glaser, 2001). As argued therein, a high quality assessment fully attends to all three components of the “assessment triangle” and their interconnections — cognition, observation, and interpretation. Work to date in developing STEM concept inventories represents a powerful explication of only two of the three critical components of the assessment triangle – cognition and observation. Failure to advance the interpretation component of these assessments, in a detailed and equally powerful manner, severely restricts the nature of the inferences that can be derived from CI data, and constrains how the interpretation of student performance might be used to guide instruction and improve student learning.

CIs tend to be highly focused on a small set of key constructs and understandings within a limited academic content domain. Unlike typical assessments of student academic achievement, CI development is grounded in various forms of empirical evidence, theoretical interpretation, and instructor judgment/intuition about student understanding in domains like Statics or Thermodynamics. Developers leverage these foundations to conceptualize and generate the question situations to present to students and to develop plausible multiple choice distractors linked to misconceptions. Thus, CIs elaborate the cognitive model regarding the nature of student understanding and its implications for the
development of *observations* of student performance. They specify the design features of the tasks based on critical forms of thinking and understanding that need to be observed. The typical result is a very clear and transparent articulation of the linkage between the assumptions about *cognition* and the nature of the *observations* to be made of student performance.

CI research and development work is weaker relative to the third vertex of the assessment triangle – *interpretation*. That vertex plays a critical role in determining how patterns of student performance can be used inferentially relative to the underlying assumptions about student cognition in the domain. CI work on the interpretation vertex generally suffers from two weaknesses that severely restrict the interpretability and use of the CI. The first weakness concerns a failure to capture inferentially the richness of the evidence about what students know and how they know it. Such evidence is contained in the pattern of choices students make across items. Most of the psychometric interpretive schemes that have been applied to item performance data from CIs have been derived from classical test theory, latent trait theory, and unidimensional item response theory (van der Linden & Hamilton, 1996). To date, little diagnostic modeling (e.g., DiBello et al., 2007) has been applied to CIs and no attempt has been made to psychometrically model the underlying conceptions, misconceptions and cognitive skills that are part of the theory underlying student performance on the CI. Thus, current statistical analyses of CIs provide only limited information for determining validity relative to the intended constructs, and little to no information for formative instructional use.

The second weakness is a failure to capitalize on a strong basic assumption that likely applies to most existing concept inventories—namely that the items tap a range of critical understandings and cognitive skills in the relevant content domain(s). The measurement instrument and its items are inherently multidimensional by design, and such multidimensionality is a strength with the potential to be applied to profiling facets of students’ understanding and generating interpretive results that instructors could use in their teaching. Typical statistical approaches fail to capture and exploit this multidimensionality.

This failure means that the linkages from *observation to interpretation* and from back to *cognition* are only of the most rudimentary form. Thus, despite the effort to design a rich, theoretically motivated set of observations, the interpretive yield from those observations is small relative to what is possible. The failure to develop and implement a strong interpretive frame supported by sophisticated psychometric techniques impedes the diagnostic application of the instrument and limits its formative assessment use by instructors. Our research therefore couples what has been done by STEM content domain experts in developing CI materials with advanced psychometric and statistical data modeling.

**Methods**

To conduct our CI research we have explicated a model of validity for classroom assessments that takes into account various forms of validity as typically discussed for large-scale, standardized tests (e.g., AERA, APA, NCME, 1999; Kane, 2004; Messick, 1989).
We focus on evidence about three complementary aspects of validity for assessments like CIs whose use is intended for instructional settings, and that are specifically designed to support classroom teaching and learning.

**Cognitive Aspects of Validity:** Given what is known about the nature of student cognition and understanding in areas of science and how it develops over time with instruction (e.g., Duschl, et al., 2007), evidence is sought on the extent to which an assessment taps important forms of knowledge and understanding, and in ways that are not confounded with other aspects of cognition such as language or working memory load. To address cognitive validity, the conceptual underpinnings for assessments like CIs are evaluated, including what they reveal about student learning and understanding of critical scientific concepts and practices.

**Instructional Aspects of Validity:** Given what is known about the nature of assessment use as a guide to instruction (e.g., Black et al., 2004), evidence is sought on the extent to which an assessment supports teaching practice and provides valuable and timely instructional information. The instructional backing and support of assessments are evaluated, including their alignment with curriculum and instructional practice, consideration of instructors' understandings and judgments about the appropriateness and utility of the assessments for instruction, and the support provided for incorporation of the assessment information into practice.

**Inferential Aspects of Validity:** Given what is known about multivariate measurement and statistical inference (e.g., Pellegrino et al., 2001), evidence is sought on the extent to which an assessment yields reliable model-based information about student performance, especially for diagnostic purposes. This includes an evaluation of the psychometric and statistical properties of assessments and their scoring approaches with regard to their informativeness for: (a) purposes of instructional decision-making, (b) improving student learning, and (c) projecting performance on external summative assessments.

This multi-component validity framework drives the assembly of multiple, linked forms of evidence for testing hypotheses about validity and for combining that evidence into a comprehensive validity argument for each specific assessment.

- **Rational Analyses.** Expert analyses are gathered of the cognitive and instructional properties of CIs relative to curricular learning goals and the literature on conceptual understanding.
- **Qualitative Studies.** Several forms of data are gathered including protocols of student thinking and solution processes, classroom observations, and instructor interviews.
- **Large-scale Studies.** Student performance on the CI questions is gathered from large-scale samples (~1,000 students) for purposes of statistical and psychometric model-based analyses.

The validity evidence reported below is based partly on data collected by the developers of the three CIs and new data collected for consideration of one or more of the aspects of validity.
validity described above. Work on each CI is ongoing. We illustrate below findings to date and directions for the future.

**Major Findings and Conclusions**

A key general finding is that the three concept inventories being studied demonstrate commonalities and differences in their conceptual frameworks, in the details of their developmental processes and in the forms and levels of evidence available for each of the different aspects of validity. We are developing uniform design and performance descriptions that address three basic questions about each CI studied: (1) What is the CI intended to measure, in particular what aspects of deep conceptual understandings? (2) What is the intended purpose and use of the CI in the classroom? (3) What arguments and evidence are provided for aspects of “quality” of the CI? Here we discuss the three inventories separately with regard to the validity evidence as it currently exists with the caveat that work is continuing to develop a more complete and integrated validity argument for each instrument.

**Concept Assessment Tool for Statics (CATS)**

The purpose of CATS is to diagnose statics concepts that engineering students typically have difficulty understanding and to identify persistent types of student errors (Hansen & Steif, 2006; Steif & Dantzler, 2004). The test consists of 27 multiple choice questions with 3 questions representing each of 9 concepts: Drawing Forces on Separated Bodies (Free Body Diagrams), Newton’s Third Law, Static Equivalence, Roller Joint, Pin-in-Slot Joint, Loads at Surfaces with Negligible Friction, Representing Loads at Connections, Limits on Friction Force, Equilibrium (Steif & Hansen, 2007). Each question was designed to test one of the 9 concepts in isolation and to require little or no calculation. Wrong answers were designed to reflect known student errors. CATS is available on-line for administration to students and is used regularly by numerous instructors. As is typical for many CIs, CATS is administered as either a pretest at the beginning of a course in statics and/or a posttest following instruction. Instructor reports give item right and wrong, total score, and student concept scores (0, 1, 2, or 3 right of the three questions for that concept). How answers connect to the specific errors and misconceptions linked to wrong answer choices are not part of the typical reporting process.

To evaluate the validity claim that performance on the inventory can be mapped against the 9 concepts designated by the developers, we have analyzed 1,372 cases of student performance data on the complete inventory provided by Paul Steif. We have performed two contrasting multivariate analyses, a standard exploratory factor analysis and a diagnostic model classification. A factor analysis with varimax rotation identified 9 factors that collectively explained 57.6% of the variance and supported the developer’s a priori categorization and claim that the assessment is tapping important and differentiable aspects of student knowledge and understanding in the domain of statics. A complementary analysis was also completed (Santiago-Roman, 2009) that showed strong diagnostic strength of the CATS instrument relative to identified facets of knowledge and understanding.

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We are comparing the outcomes of the factor analysis and the diagnostic analysis both quantitatively and qualitatively. For example, a protocol study of the CATS questions is currently under way in which students solve selected CATS questions and “speak-aloud” about their thinking. The goal is to see if students are using the expected conceptual reasoning or hold the misconception intended to be diagnosed by the distractor choices. We also are extending the diagnostic analysis to incorporate information about misconceptions and student errors linked to specific wrong answers.

**Thermal and Transport Concept Inventory (TTCI)**

The Thermal and Transport Concept Inventory (TTCI) is intended to measure engineering students’ conceptual understandings of important and difficult concepts related to heat, energy, and temperature (Miller et al., 2005). Development began with a rigorous Delphi Process whereby engineering experts developed a list identifying (a) which concepts engineering students had the most difficulty with and (b) which concepts in chemical engineering were most important to study. After multiple rounds, the original list of 28 concepts was pared down to a consensus list of 10 most important and most difficult concepts. An interactive workshop at an engineering conference confirmed these results. Content experts developed open-ended questions using the ten identified concepts. The developers formulated multiple-choice distractors using data from a think-aloud protocol study with six students. This iterative development of the test content suggests a strong degree of content validity. Psychometric analyses were conducted on the alpha and beta versions of the tests to refine future versions of the assessment. The developers designated three conceptual categories for the test content: heat versus energy, energy versus temperature, and steady state versus equilibrium. The heat section of the test has 18 multiple-choice questions, with three to six answer choices per question stem. Multiple-choice distracters are tied to prominent misconceptions. Of the 18 questions, 14 are paired questions in which the second question asks students to choose an explanation for the preceding response.

We have performed several psychometric analyses of the heat section TTCI student data (n=542) to help verify developers’ claims. (1) Most items had adequate difficulty levels, with item proportion correct ranging from 0.25-0.75. (2) The questions had discrimination indices of more than 0.2, ranging from 0.35 to 0.70. (3) Cross-tab analysis of correct and incorrect answers revealed that for paired questions, test takers were much more likely to get both answers correct or incorrect, suggesting that students generally have consistent flawed mental models of heat transfer concepts. (4) An exploratory factor analysis agreed with the original factor structure proposed by Miller et al. (2006), confirming that the data reflected the developers’ designated categories.

These initial analyzes substantiate the argument for some aspects of the quality of the TTCI. Further research is being conducted to ensure that the test items measure the intended content, including diagnostic psychometric analyses and student protocol interview studies. We also are scheduled to gather student think-aloud protocol data similar to those being gathered for the CATS.
Statistics Concept Inventory (SCI)

The SCI is intended to measure introductory statistics students’ understanding of the fundamental concepts in statistics, and is specifically oriented towards engineering students. The SCI was developed using a modified Delphi Process in which topics were compiled based on Introductory Statistics for Engineering textbooks and AP tests and rated for appropriateness and inclusiveness by Engineering faculty members (Allen et al., 2004). Questions were based on these topics and alternate response options were crafted based on a literature search of common misconceptions in statistics. The test consists of 38 questions in four areas: descriptive statistics, probability, inference, and graphics. Researchers at Oklahoma University and Purdue University conducted pilot studies and student focus groups with SCI and the test underwent a number of revisions based on these studies.

Based on 2003 pilot data, researchers determined that the SCI was a relatively reliable measure, Cronbach’s $\alpha \sim .68$ pretest, $\alpha \sim .8$ posttest (Allen et al., 2004). A factor analysis conducted on those data showed only marginal loadings on a single factor, identified as general statistical ability, consistent with the high degree of variety in question topics across questions. Hypothesis testing appeared in multiple questions, but without sufficient prevalence to produce a separate factor (op. cit.).

We have qualitatively analyzed the test and pilot findings as well as individual question content to establish overarching concept-based categories that include: Probability rules and distributions, Hypothesis testing, Large sample theory results, Interpreting graphs and tables, Important statistics indices, Confidence intervals, Elementary regression, correlation and association, Sampling and experiment design. These categories were used to construct a diagnostic structure which reflects the knowledge and understandings represented in each of the SCI questions. Next these structural findings will be compared to student data. Preliminary analyses indicate that the SCI attempts to capture students’ knowledge of a broad variety of statistical concepts ranging from probability to graphics. Thus, the SCI measures statistics knowledge at a more topical and less conceptual level.

Summary Findings. We have identified numerous areas of commonality and differences among the three CIs—CATS, TTCI and SCI—with respect to their conceptual frameworks, development processes and evidence available for quality. Our work has been animated by the three-pronged framework for assessment validity outlined earlier. A number of steps have been completed for each CI: (1) We found possibilities for building a diagnostic infrastructure with the potential to provide important information about student conceptual understanding and misconceptions. (2) We have either built a diagnostic structure or are in the process of building one for diagnostic analysis. (3) We have performed detailed conceptual and cognitive analyses to understand what is actually being measured by each inventory relative to what it claims to be measuring. (4) We either have or are gathering moderately large samples of student performance data on which to perform psychometric and diagnostic analyses. For CATS and TTCI we are performing student protocol think-aloud studies to identify students’ thinking relative to alternative claims about what the questions measure. The broad variation among the three CIs under study supports generalizability of validity evaluation approaches to other
CIs. In this context, the application of modern methods of psychometrics and diagnostic modeling has the potential to determine the diagnostic capacity of CIs and to suggest ways to improve the CIs. Diagnostic feedback is a key component for formative use of CIs in classrooms.

**Recommendations for Engineering Education**

A substantial instructional challenge within the engineering disciplines is to find practical methods for instructors to ensure that students develop deep conceptual understandings within their disciplines and to identify ready assessment methods for determining whether students have achieved these deeper understandings along with necessary topic knowledge and problem solving expertise. CIs provide a particular type of assessment that could materially improve engineering education in just these ways.

A rigorous and systematic application of a framework for evaluating the validity of assessments intended for classroom use has the potential to identify and guide needed improvements. Early findings from our examinations of existing CIs clearly indicate that CIs can benefit from standardization of methods and approaches for CI development and validation, and from application of modern psychometric methods for profiling students’ conceptual understanding, including misconceptions. Expanding the range of CI uses to include formative assessment within classes could provide a substantial improvement in engineering education practice.

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Laboratory experiments: Case study of a virtual approach

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Abstract: Laboratory experiments have always been regarded as a crucial component to scientific and technical studies. They provide a deep insight to many concepts and develop skills which are not attainable through other means. Laboratory experiments are, however, marred by a number of problems. To overcome some of such obstacles, we have implemented two pilot virtual laboratory experiments at the Materials Engineering Degree of the Polytechnic University of Madrid. This kind of experiment sought the enhancement of the students’ skills by changing their role to an active agent in the learning process as well as improving the design of more sophisticated experiments and their extension to a larger number of students.

Introduction

Due to the advent of the European Space for Higher Education, it has increasingly become necessary to develop new methodologies in order to adapt the content to the new educational model because with its implantation many changes have befallen. These new learning strategies have been developed throughout Europe, encompassing the evaluation of the strengths and weaknesses of the existing higher education systems, the definition of professional and academic skills and the implementation of new teaching methodologies. Regarding the latter, and restricting ourselves to engineering education, much effort has been devoted to methodologies such as “problem-based learning” and “project-based learning”. These methodologies emphasize the role of the student not as a passive recipient of information but as a crucially active agent in the learning process (McKeachie, 1999 and Ellis, 2005).

Laboratory experiments are fundamental in order to prepare students to practice engineering and, in particular to deal with the forces and materials of nature, as engineering is a practicing profession. They have always been central in acquiring a solid scientific and technical background, both as a complement for theoretical contents and by themselves (Feysel & Rosa, 2005). Nevertheless, a successful implementation of laboratory experiments is not always feasible. Some of the most relevant problems can be listed:

- High number of students. In some degrees the total amount can be above 600-800, which leads to overcrowding and dramatically reduces the interaction with students.
- Limited financial resources for the development of laboratory experiments.
- Limited space for the proper development of the laboratory experiments.
• Limited number of available teachers for the correct teaching of the laboratory experiments.
• Lack of motivation of teachers responsible for the teaching of the laboratory classes, as this is a very dull and repetitive teaching.
• Lack of motivation of students who do not have incentives to find results due to they know in advance (step by step) what to do and the result they must obtain. The results usually end up by copying from each other and making clone reports from the teacher.
• Difficult renewal and adaptation of the experiments at the new training needs and methodologies due to economic and immobility of teachers.
• Difficulty in correcting reports of experiments and the individual interaction with students to discuss the results.

In short, traditional classroom experiments of the first grades often end up, in eyes of students, in a mere formality to pass the subject. Moreover they require a great amount of economic resources, human and material that hardly ever justify their limited contribution to the student learning.

The development of simulators and virtual labs practices can strongly contribute to correct this whole situation (e.g. Harms, 2000; Trindade, Fiolhais & Almeida, 2002 and Ma & Nickerson, 2006). The advantages of using these elements in teaching are evident:

• Decrease of operating costs. Once the set-up is completed, few resources are needed for its maintenance
• Updates or modifications of the experiment can be easily implemented.
• Possibility of customized tasks or initial data for each student so that every experiment is different from the rest and results can no longer be immediately predicted. This would avoid copying of reports and makes conclusions original for each experiment.
• Possibility of graduating students learning by introducing key issues during the practice, so that if they do not pass each one, they have to repeat that module (or ask the teacher) until they have reached the knowledge level desired by the teacher.
• Possibility of presenting environments and/or experiences that in real life that would take a long time or would not be feasible.
• Possibility to perform many tests at virtually no cost
• Possibility of multiple accesses of students without impairing the quality of teaching or learning.
• Individual or group work of students
• Possibility to practice in supervised remotely groups from place and time that is most convenient for the student.
• Promotes the use of information technologies by students and teachers.

Regarding this case study, the goal was the implementation of two pilot virtual experiments concerning the observation of dislocations and the tensile behavior of a polymer for the subject “Structure of Materials II” which has taken place during the second semester of the degree in Materials Engineering (academic year 2010/2011). A
second step would imply the development of two additional virtual experiments for the next academic year. The choice of such experiments, besides their scientific interest, which will be commented later, is based on the relatively complex preparation of the specimens (for the case of dislocations observation) or the long time required for the tensile tests (several specimens tested at different strain rates and temperatures), which make these experiments in its classical version available only to a reduced number of students. This was the case in which both experiments were first introduced for at our University (academic year 1997/98, for a group of 15 Master’s degree students).

On the one hand, understanding dislocations is a key issue for students of Material Science and Engineering. Dislocations are crystalline line defects which are responsible for the plastic deformation of a crystal. There is a complex phenomenology involving dislocation creation, dislocation dynamics and annihilation, which in turn are crucial in order to understand the hardening mechanisms in metals (Hull & Bacon, 2011). Moreover, it is highly desirable that students be familiarized with microscopy and the observation of micrographs already during their first year at university. On the other hand, tensile tests, being the most common mechanical tests, are central to the formation of future engineers. In particular, tensile tests on polymers (PMMA) can shed light on phenomena such as glass transition, necking and strain localization, crazing and micro-cracking, to name but a few (Ramos-Carpio, 2007).

**Methodology**

First, students are provided with an experiment guide containing some of the theoretical foundations and the experiment procedure together with the key questions that at the end should been answer in a final report they must complete. Some additional material such as pictures and related bibliography is included. This point is relevant because the information contained in the experiment guide is not complete, so each group of students is encouraged to conduct their own research on the suggested issue.

A video is recorded and edited by the teaching staff. In the case of dislocations, this video begins with a general introduction to the experiment and continues with a step by step development of the practice, where a monocrystalline specimen made of NaCl is prepared and a Vickers indentation is performed on it. The video is embedded in several parts inside a PowerPoint file. This file also provides a complement to the theory with images and numerical simulations on dislocation dynamics. The students can download it during a certain period of time. Customized experimental data is generated by an algorithm through a scaling parameter based on the students’ personal code. Among these customized data, a magnification number is attached to an array of micrographs, and students are asked to measure elements such as the distance between surface steps, indentation footprint size or the density of dislocations in a certain area (see Fig. 1). The methodology is identical for the tensile test on PMMA. Here, the scaling parameter is used to generate a file containing the specimen dimensions, cross-head displacement, extensometer measurements and load. Students are asked to obtain the nominal and true stress-strain curves and to describe the deformation and fracture mechanisms from pictures (Fig. 2). For both experiments, students are expected to process the information
according to the experiment guide and to the results of their additional bibliographical investigation in order to obtain results and conclusions necessary to complete a written report where the theoretical concepts are to be linked to the experimental observations.

Figure 1: Example of a slide depicting the indentation footprints and the dislocation pattern around them

Figure 2: PMMA specimen after a tensile test at 110 ºC

**Results**

During this year, the whole group of first-year students of Materials Engineering, accounting for a total of 75 people, has been able to remotely perform the aforementioned experiment. After finishing the reports, some students commented on the MOODLE-supported blog of the subject. Some of these comments are interesting:

- “Better than the usual experiments, I could work late during the night”
- “The powerpoint presentations, although somewhat fast, are easy to follow, and you can watch them as many times as you want”
- “I had to work harder [than in the usual experiments], because I had to do the online research”
- “They are interesting, and you don’t waste any time”
- “Can anybody tell me how can I import the txt files into Excel? I got a mess”
- “I’d like to see the real thing”
As can be observed, they provided us with an extremely useful feedback. An explanation about transforming raw data into other formats should be included and the timing of the videos could be slowed down for the next version. Nevertheless, the feedback is generally very positive and outlines some of the advantages of virtual experiments, namely their flexibility and the active role of the student, not to mention the impossibility of cloning the results. Quite paradoxically, it is worth noting from the last comment that virtual experiments can stimulate the student's interest about the real (standard) experiments.

The existence of earlier results (marks of the written reports corresponding to the 1997/98 standard experiments) suggested the possibility of quantitatively compare standard vs. virtual experiments, but the samples were too dissimilar (15 Master’s degree students vs. 75 first year students) and this idea was discarded. However, we were able to compare the overall performance of the students in the subject with respect to last year’s, where there the virtual experiments were not present. The results are depicted in Fig. 3 and Fig. 4 (overall marks ranged from 0 to 35):

Figure 3: Overall marks corresponding to academic year 2009/2010 (without virtual experiments). N=58
Although the average remains constant (17 points) for both years, there are significant differences. First, the ratio of students dropping down the subject has decreased from 10% to less than 5%, while the percentage of students who pass the subject has increased up to 75%. The minimum mark grew from 6/35 (2009/10) to 10/35 (2010/2011) and the threshold for passing the subject has also increased from 12.5 to 14 points. The mark distribution for this year is more concentrated, particularly as a result of the better marks obtained by the weaker students, who would have benefitted by the extra motivation arising from the virtual tests.

Conclusions

Virtual laboratories are not free of problems (Cooper, 2005), but the advantages of this "virtual experiment" approach are manifold. First, sophisticated experiments can be designed and there is no limitation to the number of students. In our case, 75 students were able to successfully complete two complex experiments which had been conceived for a maximum of 15. There are no limitations deriving from timetables or physical location. The teaching staff showed a high level of satisfaction due to the fact that standard laboratories demand a large amount of time devoted to highly repetitive tasks. Students have outlined the flexibility of this approach and have welcomed its use. Although not conclusively proven, virtual tests seem to have improved the overall performance in the subject, particularly those students with lower marks, who are more sensitive—or even prone— to lack of motivation. This approach avoids excessive guidance and makes space for the students' initiative, therefore promoting their autonomous learning. Enhancement of the students' IT skills can be considered a beneficial side effect of the virtual experiments. To sum up, and taking into account that this has been a first attempt, the desired transition from a passive essential student profile to an active remote student one has been achieved to a considerable extent.
Future work

Two additional experiments will be designed for the next academic year in order to complete the experimental curriculum of the subject. A thorough survey will be conducted to assess the acceptance and degree of satisfaction of the students with the virtual experiments. Additionally, this year experience will allow a homogeneous comparison of results to quantitatively estimate the effect of the experiments. Once the experiments will have been satisfactorily evaluated, the collection of virtual experiment would be ready for OCW storage and online courses. Access can be granted to students not even belonging to the university. Finally, together with other groups in our University, we are studying the possibility of moving one step forward towards virtuality and implementing the experiments in a full virtual environment such as Second Life.

References


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An interactive platform for IA Games

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Abstract: This paper introduces two platforms for the experimentation in games strategies within the study of Adversarial Search, part of the practical curriculum in Artificial Intelligence. The first one is a platform for performing tournaments. AI students are asked to send automated players for a given game, which are confronted against each other and ranked in order of performance. The platform was successfully used during the last two academic years by over 200 students per year, and performed over 100,000 confrontations/year. The second is a platform for executing P2P games in real time between remote players. It is oriented to the performing of individual matches and includes social network characteristics. This experience shows that the potential of such initiatives is very promising, since they not only stimulate the interest of the students for experimentation and learning, but also create a level of engagement that exceeded our and the student’s expectations.


Introduction

This paper reports a real educational experience in Artificial Intelligence that may be of interest for scholars in engineering education. It was inspired by ideas on active learning (Dilworth, 1998; Dunn, 2002) with the purpose of increasing the student’s interest in our subject. There is no consensus about the influence of competition on motivation, but multiple experiences show that the influence can be positive (Marra & Wheeler, 2000; Cantador & Conde, 2010). This work takes place within the context of the European Higher Education Area (EHEA), which provides engineering educators the possibility to interact with and to provide continuous assessments to students (Pérez-Martínez et al., 2009; Crosier et al., 2006).

Artificial Intelligence (AI) has a rare characteristic that sets it apart from most disciplines in Science and Engineering: its objective is a moving target and its definition an ongoing one. Most of the problems it deals with are open problems, where only incomplete or partial solutions exist. Certainly in AI there are well established concepts and techniques that could be taught using any other educational paradigm, but the study of Adversarial Search, where two or more contenders are competing to out-smart the other within the rules of a game, seems a good candidate for discovery learning. The subject to learn is the use of heuristics to estimate the goodness of a particular game movement considering the situation of the board and the options of the contrary. This is an open problem because no ultimate solution is known and because the goodness of any move is limited by the ability...
of the contrary. Therefore, the process of individual discovery seems to be as important as the techniques to be taught. In order to provide a realistic context where students can test their players’ goodness and which could motivate them to work actively in this task, a tournament platform was implemented.

The next section introduces the objectives of this experience. The methods section describes the implemented platform and the data gathering process. The results section shows quantitative measures for the two years in which the platform has been used and presents our interpretation. The conclusion resumes the findings and their relevance. The last section describes our current activities including a P2P platform and our plans to use it in future work.

Research Objectives

The exploratory study described in this paper had three main objectives: 1. Stimulating the learning process; 2. Stimulating original thinking; 3. Understanding how time pressure affects both.

We can evaluate the first by measuring the amount of work produced by the students and comparing it with the previous situation. We can evaluate the second by confronting the algorithms produced for the tournament and the algorithms produced in previous years against some reference. It would be nice, but unfortunately we cannot confront directly the algorithms produced for the tournament in one year with those produced in previous years, because the games they are playing are not exactly the same. Indeed, in order to avoid plagiarism between years (or from external sources), we take two precautions: firstly, the game we propose is a modified version of the game known in real life, so that comments, strategies or even the code available on the web may suggest ideas for successful players, but cannot be simply copy-pasted. Secondly, we modify the game from one year to the next in such way as to guarantee that the strategies used by successful players from previous years cannot be used so successfully as to represent a significant advantage in the current year. Finally, we can evaluate the effect of time pressure by observing the performance of the course under tighter time constraints. The time available for the competition was reduced to analyze this point.

Methodology

Our exploratory study took the form of a longitudinal case study conducted in the environment of an actual university class during two academic years. Students were requested to submit code, which was parsed and evaluated formally. If this evaluation was successful, the code was evaluated functionally by confronting it to its peers. Since the whole process is computerised, each action taken by the students or their players was recorded: timestamps of deliveries, identity of the opponents, result of each game, number of moves needed for game completion, primitives used within the code, errors & warnings, etc. As a result of each game, points were given or taken from the overall score of each player and the positions of the players in the ranking oscillate. In general, better players have an ascending trend and worse players a descending one. After completing the
semester, students were asked to fill a questionnaire about their experiences with the tournament.

Participants

About two hundred university students participated each year in this study, grouped in teams of two, i.e. 100 teams/year. This exercise was part of their AI course in their 3rd or 4th year of studies. The total time available for the exercise was about 5 weeks. The work required to solve the proposed problem was estimated in 3-6 hours, but no limits were set nor indications were given in regard to the dedication expected, although both, the data log and the questionnaire show that most students dedicated much more time to this task.

The Tournament Platform

A game is introduced and the students are asked to practice until they get familiar with its rules and basic strategies. Four automatic players (Lisp code) are provided with two goals: serve as counter players for the students and as examples of possible strategies. The students can play either by themselves (manual input) or by writing code (automatic input). One of the four automatic players always plays randomly, so its games are unpredictable. The other three players are named bad, average and good, corresponding to their respective proficiency. Soon the students learn that playing by themselves they are only able to win systematically against the random player, and often against the bad player, but rarely against the average player. However, they can produce code that equals the average player. Defeating systematically the average player is a little more difficult and defeating the good player is much more difficult. The first objective of the exercise is quickly achieved: provided they work within a given framework that is part of the teaching, students can easily produce AI code able to perform a task that has proven very difficult for a human.

The second objective of the exercise is to explore options and produce the better possible playing strategy. Since their own code is already playing beyond their human capabilities, the only way to test new ideas is to confront algorithms with each other. To facilitate the games in an orderly form and to provide an impartial ranking of the players, a tournament platform was implemented. The tournament platform is permanently available for the submission of new players. Periodically the platform will confront the batch of new players with the older ones. The results of these games are used to update a ranking of the players based on their score, which is published on the web.

The first requirement of the system was to guarantee the correct timing, authenticity and non-repudiability of the submissions. Timing is not important per se (students have weeks to present their players), but is used to limit the number of submissions per day, so as to make it more difficult to perform the activity by trial-and-error. Authenticity is needed to ensure that each player really belongs to a certain student and not to a rival. Non-repudiability is required in case of student complaints, since grades are assigned according to their position in the final ranking. This has been achieved by coding the file names and using private passwords.
The tournament management system should allow any type of game. This is achieved by decoupling the game mechanics from the functions of submission management, opponent’s selection, scoring, ranking updating and publishing. The implemented management system (majordomo) satisfies all these requirements and, in addition, can manage several different games simultaneously.

Since the student submissions (players) are computer code that must run on the same server where the tournament manager is running, system’s security and stability is a major concern. A syntactical analyser or parser was independently developed to inspect the code before its execution. The parser detects format errors as well as the use of functions that voluntarily or involuntarily could damage or jeopardise the system.

A major requirement to keep alive the interest on an on-line tournament is the ranking refresh rate, i.e. to publish results timely, shortly after the submissions. On the one hand, the only way to guarantee that each player occupies its true place in the ranking is to perform a round robin competition (Harary & Moser, 1966). However, there is a continuous flux of players entering and abandoning the competition, so performing a round-robin competition before every update of the ranking is either not practical or impossible, due to the amount of computing involved. Computation grows geometrically as N^2 with the number of players N, and therefore a round robin competition is not scalable. To avoid both problems we implemented several scoring systems inspired on Elo's rating for chess, which were tested along thousands of simulated games. These simulations showed that given a pre-existent ranking produced by a round robin competition amongst a small group of players, say 20, we could place any new player in its correct position (i.e. the position it would have reached in a round robin competition) with an average error of 5% after no more than 40 games against selected players. This situation keeps quite stable for a few hundreds of new entrants, but it shows a small but accumulative degradation in accuracy, especially for each old player that abandons the game or when there is a large difference between old and new players in number of games played. To overcome this degradation, the tournament refreshes the ranking by performing a round robin tournament every several days, after midnight. In some cases this would produce significant changes in the position of a player, which was often followed by complaints (students followed very closely their positions in the ranking). The technique used exceeds the scope of this article, but we can affirm that it solves the problem in linear time and therefore is scalable to a large number of players, at least for a period of time. Every 60 minutes, the new entrants are confronted to the old ones and assigned a position in the ranking. This process takes only a few minutes, so it could be repeated much more often. It was chosen not to do so for the reasons expressed in the next paragraph, despite the sour complaints of some students.

Another issue related to the previous one is the number of submissions. In our experience, most students tend to delegate a great part of their intellectual tasks to the computer, disregarding careful planning and reflection. The result of this continual trial-and-error programming style is often code full of ad-hoc solutions, not well-thought and lacking structure. In an attempt to correct this tendency, the number of players that the students can submit to the platform is limited to 3 per day, and must wait up to one hour to see the...
results. This is not based on technical limitations but to reinforce the reflexion and careful planning of the strategies and to limit trial-and-error. This restriction also invites the students to start their experiments early: for each day that they don’t play, they lose game options. Late-comers should have a difficult time catching up.

Data Analysis

The collected data have been aggregated using string processing functions (regular expressions) and processed using basic statistical spread sheet functions. To evaluate the work and results, datasets have been produced for deliveries per student and deliveries per day, which, combined with the points obtained, are an indication of the results achieved. In addition, we have a measure of the effectiveness of the players: the so called good player is not using any strategy related to the particular game; instead, it is just using the same plain strategy used by the average player, but with one more depth level. This serves two purposes: it is a rough sparring partner for the student players and a bar level that we can use across years. As mentioned earlier, in general we cannot confront players from different years.

Although the problem in its current form has been solved by the students since 2007, the tournament has only been available since 2009. We can compare however all four years by using the bar set by the good player. Unfortunately this is the only objective measure of quality, but the results are quite clear nevertheless.

Results and Discussion

The game strategy problem was presented to the students at the beginning of December and the closing time for submissions was early January (15-1-2010 and 10-1-2011). One can appreciate the similarity between the curves and their adaptation to the major festivities, with clear drops in number of deliveries in Christmas day and January 1st. Likewise, almost nobody started working on the problem before December 20th (Fig.1) (begin of the holiday season). The real start is clearly the day after Christmas. The submissions per year remained constant at 900, averaging 9 per team (Fig.2).
Despite the 5 days shorter deadline in 2010 the students did the same amount of work (900 players) in 20% less time, while delivering comparable quality: 5% of the players passing the high bar and 80% the low bar. Furthermore, the response pulse in 2010 shows better planning. The peak of deliveries happens a few days before the deadline, instead of the last minute as in 2009. Figures 3 and 4 confirm the same observation from a different perspective. Students in 2010 reach similar quality with fewer submissions in fewer days, i.e. their efficiency is quite higher. A questionnaire was sent to the most outstanding cases, which confirmed that the best performers did a lot of analysis before submitting every player. Finally, by plotting the starting date of the deliveries against the final points obtained we observe in both years a clear correlation between starting early and getting a higher score. In addition, the plot (not included) shows that in 2010 students started earlier although they had less time.

Comparing the two years with tournament with the situation before, where students had to produce just one player, which was graded not by comparing it to its peers but just as it performed against several bar levels, two things become obvious. Firstly, the quality of the players is much better, since no player produced earlier had ever passed the bar, while in the two years of the tournament 5% of the players did pass the bar each year. Secondly, and this is the cause of the previous result, the time invested in the exercise has increased from the estimated 6 hours before the tournament to an average of 20 hours or 10 days (11.5 in 2009 and 8 in 2010) since the tournament was introduced. Considering that the value of the player for the final grade has not changed, we must conclude that the increase in dedication was stimulated by the tournament.

![Figure 3: Efficiency 2009](image1)

![Figure 4: Efficiency 2010](image2)
Conclusions

This experience has created enormous interest among the students, some of which dedicated to these activities much more time and effort than both, faculty and students, expected. A result of the longer time dedicated to the activity is the quality of the results, clearly superior to previous years. The combination of a competition with a tournament platform creates a need and provides a medium to motivate work and to stimulate experimentation, resulting in better and more original results. The success of the first platform created requirements for a second platform (P2P platform, described below), which was developed partly based on student demand.

However, while the interest in competition is supported by 75% of the students, 20% of the students manifest strong reluctance to have their grades linked to such a competition. Both quantitative and qualitative data show that competition is a strong motivator for learning, but should not be too strongly coupled with grades.

Finally, we want to stress the fact that a moderate time pressure resulted to be a stimulus for careful planning and reflexion. This relevant circumstance is consistently confirmed by results from three different observations: submissions per day, efficiency and starting date.

Current and Future Plans

The tournament model has been well accepted by the students and has stimulated their interest in the subject. The utility of the tool from an educational perspective has been very positive, but it has a limited capability as a research tool, since the information that can be obtained is reduced to several files of code per day. We can extract some approximated guess about the amount of work invested by the students and about the quality of their learning, as we have done in this article, but to fully understand the students learning process, their trials and perhaps the origins and flows of innovation, we need much richer information.

It was a suggestion of some students to have a system to challenge each other in a selective fashion. They asked to be able to confront their players against a particular opponent instead of just waiting for the ranking to give them an overall score. At the same time, we were considering to evolve the system to allow multiplayer and collaborative games. Therefore, during the current course we have implemented a new platform that fulfills both requirements and opens a new way of looking at the problem. While the tournament will remain the official ranking, the P2P platform will play the role of a chess club, where members can informally train themselves before going to the tournament.

The new platform is technically and functionally independent from the first, and it uses P2P techniques to allow individual games to take place in real time between two or more players from remote locations. Its most relevant characteristics are:
• It provides students with a tool to improve their players by selective confrontations, while protecting their code by exchanging only moves, not algorithms.
• It allows multiplayer and collaborative games, which enable many new types of strategies.
• It allows manual and automatic games and the possibility of focusing on specific moves or problems.
• It has social network characteristics, where gaming plays the role of relationship. It is scalable to very large groups.
• It provides much richer information for education research purposes.

The P2P platform has been successfully tested during the academic year 2010/11 by a group of enthusiastic students and will be used by all the students next year. This will allow us to gather much more data, which we expect to use in future research.

References


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Learning speed evaluation of first year engineering students

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Abstract: In this paper it is tested the hypothesis that some dynamic variables, especially energy, power and velocity, can be applied to the better understanding of learning processes relevant to engineering students success. Is in this context the Center for Research in Creativity and Higher Education, has designed a psychometric test battery that intend to measure some variables that may be pertinent. These variables were defined considering their possible biological substratum. They are mind power (MP), mind resistance (MR) and learning speed (LS). The instruments have been applied to 93 students, enrolled in Engineering Technology Programs; obtaining a Cronbach's alpha of .88 reliability. The main outcomes are correlations among MP and LS, and MP/MR2 (ρ=.40).

Results shows that the tests are able to detect significant individual differences as to all dynamic variables considered. The relation between learning speed and academic success has not been yet tested.

Introduction

Chilean universities are nowadays facing a significant increase of tertiary education applicants and subsequent enrolled students. In a decade national registration has climbed from 500,000 students up to about 800,000. New students come mainly from lower income segments of the population. Engineering is strongly demanded due both to its higher salary and social status associated. However, as in other parts of the world, in most Engineering colleges drop-out rates are large, especially in the first year. Several projects are being developed aiming to correct this problem. Academic, economic, social and health variables, among others, are being considered for diagnosis.

At the moment, there are no studies to determine what the main causes of the first year drop-outs are. Arising ideas have been related to inaccurate admission tests for tertiary education in Chile; the tests could be failing to diagnose the necessary skills for a certain program.
The Center for Research in Creativity and Higher Education-CICES has been involved in studies aimed at enhancing institutional knowledge about learning, as a way of improving retention rates. A novel approach has been chosen as complementary to others already in course. This approach relates at developing and applying some measures of learning processes that can be associated to what the authors call “Learning dynamics.” Here “dynamics” is meant to encompass concepts such as speed, time-rates, energy and power (energy per unit time), mainly. We have worked around a pivotal hypothesis: in some academic programs student success is dependent, among other factors, on learning speed and other related variables. This is assumed to be applicable to engineering where novice students have to learn a large number of new and complex concepts in short time. At this stage of and ongoing research the main goal is to verify whether or not it is possible to detect significant individual differences as to learning dynamic variables. Such differences, according to the main hypothesis, should be related, at least in some cases, to learning success in engineering. In this paper are presented some results concerning the identification of individual differences.

A set of tests has been developed for measuring learning speed, mind power and mind resistance. These variables are supposed here to be related as in other physical systems. The research outcomes have demonstrated, in all groups tested, that significant individual differences appear referring to test performance.

**Background**

Researches referring to individual cognitive differences have historically been made regarding three points of view: psychometric structure of individual differences (Vernon, 1950); predictive validity of evidence gathering instruments (Deary, Whalley, Lemmon, Crawford, & Starr, 2000); and supposed causes of individual differences in terms of psychometric and cognitive components, and biological rates (Deary, 2001). This last approach is the most relevant for this research.

Many studies have shown some degree of relation between peripheral nerve conduction velocity and intelligence, or other cognitive sub-abilities, obtaining interesting correlations (Rijsdijk, 1997), some have referred to it as efficient use of cerebral resources, ie. mental power (Reed, Vernon & Johnson, 2004). Other researchers have proposed that personal differences on mental capacities for executing specific tasks depend on factors like glucose consume, and brain signal’s speed, among others. This would explain differences on intelligence (Vernon et al., 2000).

All these studies intend to evaluate the mental capacity required to perform in specific tasks. In the engineering education domain, this gains relevance; since study programs are configured around learning outcomes, such as competences (Letelier et al., 2009).

Thus the challenge arisen for this study, as it has been anticipated, is to assess people capacity to use brain energy, specifically regarding three concepts: mind resistance, mind power and learning speed. We suggest that correctly using brain energy has a main role in ability development, task accomplishment, and learning; three aspects that impact in first year students’ academic performance.
Aims

It is expected to prove the specific hypothesis of an existing positive correlation between learning speed (LS), and mind power (MP); and a negative one between learning speed and mind resistance (MR), as shown in the following formula (1).

Hence learning speed should increase on a subject with a high punctuation on mind power, and should decrease on someone that shows high punctuation on mind resistance. Also, as already indicated, in this expected individuals a given course will differs as to these variables.

The following assumptions have guided the measurements:

- It is possible to design an apply instruments for measuring mind power
- It is possible to design an apply instruments for measuring mind resistance
- It is possible to design an apply instruments for measuring learning speed
- There is a positive correlation between LS and the ratio between MP and MR

Theoretical framework

A basic model to explain cognitively tasks achievement is the one below (Figure 1). It emphasizes on the biological substratum, knowledge and experience. The biological substratum is the biological base of the brain; it provides the energy and the physical-chemical processes that are necessary for cognition. “Knowledge” has been described largely; and “experience” refers to the practice of the ability, as in other cases, the more a task it's practiced, the greater the ability.

![Figure 1. Basic model to explain cognitively tasks achievement.](image)

The three leading concepts in this research: mind resistance, mind power and learning speed are explained on the following paragraphs.
1. Mind Resistance (MR)

There seems to be no comparable scientific antecedents for ―mind resistance‖ linked with the concept of brain energy. Nevertheless, it's an essential concept to understand and assess the differences in the abilities shown by individuals.

When using abilities to perform a task, the brain uses energy. Thermodynamically speaking that is necessary because there is a work being done, and there are some resistances to it. The nature of those resistances in the mind is highly complex; and in this study it is going to be approached in a macroscopic way, within the limits of what can be supported and then verified.

To seize this concept the following domains have been considered as working assumptions: working memory, general knowledge, and non-trivial associations (Cowan, 2010; Reid, 2009; Kozulin, 2011). Here it is assumed that mental organization and ability to work mind contents reflect mind resistance to the use of cerebral energy.

2. Mind Power (MP)

Recent studies have related the concepts of brain level energetic efficiency and higher index of g intelligence, particularly gf (fluid intelligence) (Jensen 1998). Others have found negative correlations between psychometric measured abilities and cortical activation volume (Just, Carpenter, & Miyake 2003; Newman et al 2003), which allude to efficient energetic use concepts.

Other interesting phenomena in this context, is the synchronization or functional connectivity, referring to the indirect evidence regarding communication and collaboration among different zones in the brain (Horwitz, Rumsey & Donohue 1998). Mind Power should be positive related with this idea, because the speed for achieving different tasks would depend on the time elapsed to synchronize the appropriate zones to develop the specific kind of task (e.g. Broca's and Wernicke's zones show a cortical activity increment when the complexity of a text is raised) (Just et al 1996).

Studies already cited indicated that more expert people use more efficiently cerebral energy, ie glucose. That this, their use less energy when executing known tasks and are able to convoke cerebral energy fastly for new tasks.

3. Learning Speed (LS)

Learning speed was measured directly by means of learning task designed to be accomplished in given time intervals. These were chosen so that, at two different moments, students should ask questions related to understanding and reasoning.

Methodology

1. Reliability

The PM test was applied in all to 232 students last year high schools students (7 High Schools) and to 287 first year university students (7 programs) prior to its application to
the reported sample. This procedure lead to an acceptable level of confidence on the tests capacity for measuring mental ability for responding in given times to novel tasks.

2. Sample

The sample was composed by 93 students (64 male and 29 female), exhibiting an age range between 17 and 25 years; being the age average of 18.6, with a standard deviation of 1.25. The target students are currently enrolled in Technology related programs at the University of Santiago of Chile.

3. Instruments

The tests were constructed considering the three main concepts: mind resistance (T1), mind power (T2), and learning speed (T3). The first one, T1, is a subtest that assesses the capacity to organize ideas, use general knowledge, use working memory and make non-trivial associations, on a limited time period. Mind power, T2, confronts the student with the challenge of answering five simple new tasks, that don’t require using previous knowledge, in a short amount of time. The third subtest, learning speed, T3, that intends to measure the ability to quickly learn something in a determined amount of time, was designed through two main axes, comprehension and reasoning.

In order to ensure the instrument reliability a Cronbach’s α (alpha) has been applied to the whole test, producing a .885 for the obtained results, which, according to Schmidt (2006), is considered good enough in this kind of studies.

<table>
<thead>
<tr>
<th>Cronbach's Alpha</th>
<th>Cronbach's Alpha Based on Standardized Items</th>
<th>N of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>.885</td>
<td>.779</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 1. Reliability Statistics

These instruments present an acceptable discriminating validity, given the correlations observed in the chart above. The obtained Pearson indicators on the different test sections (T1, T2, T3) show a correlation degree, stronger between mind power (T2) and learning speed (T3) (p=.34). However, it has been ruled out the possibility that they could be measuring the same variable, considering that the correlations don’t exceed .38.

4. Procedure

The test was applied to two different courses, namely first year program in Personnel Administration, and first year program in Industrial Automation at the Faculty of Technology. In both processes the protocol was thoroughly followed in order to avoid disruptions on the data. The test application took 2 hours and a half, with 5 minutes break.
between each section of the test. It was taken during class scheduled time, with the Faculty of Technology’s approval.

**Findings and conclusions**

Among the relevant findings of the research, it has been proved the discriminating capacity of the instrument. It can be observed in Figure 2 (a) how individual differences in mind power among individuals appear.

On the other hand, Figure 2 (b) exhibits a histogram with mind resistance results, keeping the order given by rank obtained by mind power distribution. It can be noticed that they have different distribution; this proves that the subtests (MP and MR) are assessing dissimilar mental capacities. Moreover, Figure 2 (c) indicates that the ratio between mind power and mind resistance shows similar discriminating level as in the case of mind power behaviour.

![Figure 21. (a) Histogram of scores on the mind power test. Sorted from lowest to highest. (b) Histogram of scores on the mind resistance. (c) Histogram of scores on MP/MR in Technologies careers.](image)

As it can be seen in Figure 3 (a), there is a stronger correlation between the results of MP and LS (\(\rho=.380\)). Similar correlations have been observed among mental abilities that generate personal differences, such as Working Memory, Verbal and Spatial Abilities (Deary 1998).

In Figure 3 (b) are shown correlations between LS and a series of ratios between MP and MR: MP/MR, MP^2/MR, MP/MR^2. The latter two are designed to strengthen each variable correlation and support a study of Pearson index behaviour, obtaining as best result (\(\rho=.397\)), with the MP/ MR^2 ratio.
Thus the mathematical expression that better explain the correlation is (3):

As it can be appreciated in Figure 4, a linear correlation would be weak ($R^2 = .157$). Though a rough analysis could show that the number of observations responding to a direct relation (quadrant I and III), is greater than those that do not respond to it (quadrants II and IV). In first and third quadrant, is possible to find 61 students (65.3%), in the former are gathered students with high scores in T1 (RM), and also the ones in the ratio MP/MR$^2$; in the latter quadrant is reproduced a similar phenomena, but considering the low scores.

The results show that the designed instruments can have the potentiality for discriminating individual capacities, mainly cognitive, that are supposed to influence learning.

**Discussion**

This paper shows results of an intermediate stage of a research aimed at validating the pertinence of learning dynamics variables as predictors of engineering student success.
Results so far are restricted to validating the hypothesis that significant individual differences exist when strict time constraints are incorporated in mental performing and learning tasks.

In order to achieve the designed goal of obtaining scientific information that may be useful for better addressing the problem of engineering student drop out, it is still necessary to cover some extra stages. Some of these are:

i. It is necessary to validate the concepts of mind power and mind resistance through further testing ad, and additionally, complementary measures of cerebral performance.

ii. The relationship between learning velocity and academic success in engineering should be investigated.

iii. The relationships among mind power, mind resistance and learning speed need to be subject to more intensive testing. These relationships may be relevant for designing academic aids for students with learning problems that otherwise may not surface.

The authors feel that the present is a promising, albeit complex and rather long term, field of inquiry. It seems proper that engineering variables, such as dynamic variables, should be tested as possible sources of novel educational knowledge.

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Negotiation Games: Acquiring Skills by Playing

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Abstract: This paper shows the research done at the School of Industrial Engineers (ETSII) of the Technical University of Madrid (UPM), in two consecutive academic courses. In this negotiation game each team is formed by three students playing different roles, with a different degree of complexity. The game is played three different times changing the conditions and doing the Zones of Possible Agreement (ZOPA) smaller so the negotiation is going “harder” and it was more difficult for the team to achieve an agreement. Roles were distributed according to the student’s experience, since it was understood that difficulty of the roles was different, especially when there was set a time limit for negotiation. The combination of playing and training has shown that students without particularly good negotiating skills at the beginning of the experiment attained better final results than those who have natural negotiating skills, but no benefit of training.

Negotiation on engineering education

Negotiation is a very important fact in whole life activities, but it became a key facet of engineering work and projects. Negotiations take continually place at any stage of a project, and so, the ability of engineers and managers to effectively carry a negotiation is crucial for the success or failure of projects and businesses [Dzeng et al., 2004; Ren et al., 2002; Murtoaro et al., 2007; Yaoyuenyong et al., 2005]. Negotiation is defined as a joint decision-making process of two or more parties working together to reach a mutually acceptable agreement over one or more issues. It involves communication, direct or tacit, formal or informal, between individuals who are motivated to converge to that agreement for mutual benefit [Yaoyuenyong et al., 2005].
Although it is important for both parts to reach an accord, many times there is not the
willing to cooperate or exchange information, because they fear that the counterpart could
take opportunist advantage of the information they transmit [Raiffa et al., 2002].
Negotiating partners need then to balance cooperative actions with competitive ones,
what is usually referred to as the negotiator’s dilemma [Hindriks et al., 2007; Fujita et al.,
2008].

The analytic approach of negotiation fact [Murtoaro et al., 2007] is based on three major
fields of study, all of them related to the ideal of rational decision making: game theory,
decision analysis and behavioral decision theory.

Quality, schedule or other facts are subjected to be negotiated, individually or as a part or
a group, on engineering transactions, but from all of them, price and delivery time used to
be the most important one in the majority of the negotiations, specially in construction
projects [Fujita et al., 2008; Pacios et al., 2011]. When the highest price that the buyer is
disposed to pay is greater than the lowest price the seller can accept, the agreement is
possible. The range between these two prices is called ZOPA (Zone of Possible Agreement)
[Yaoyuenyong et al., 2005].

Other concept generally utilized at negotiation is the BATNA (Best Alternative To a
Negotiated Agreement) [Murtoaro et al., 2007], that can be used as an effective way to
establish the reservation price [Fisher et al., 1991]. The fact of establishing a realistic
reservation price based on BATNA before a negotiation take place, not only can it increase
the possibility of a successful deal, but also improve one’s confidence and bargaining
power on the negotiation table. BATNA is even more useful when several issues are
included in the negotiation, since different ZOPAs would exist and the negotiation process
will become more complex.

Although negotiation skills are extremely important for engineers, it usually receives little
attention on career’s programs, as it is generally accepted that this kind of skills can be
only learned through experience and observation [Hindriks et al., 2009; Smith, 1992;
Brzostowski et al., 2006]. Negotiation knowledge is not likely to be taught only at
conventional classroom with expositive methodology, as the students usually find it
boring and without motivation enough to participate actively [Yaoyuenyong et al., 2005;
Jiau et al., 2009]. Recent educational programs include the acquisition of competences in
coordination with the acquisition of scientific knowledge.

Learning negotiations skills by playing. Methodology

The role play method is generally recognized as more suitable to increase the trainees’
skills [Hindriks et al., 2009]. At this technique, the students are asked to play with some
others assuming a role in an adapted engineering negotiation. They are given some
common information about the scenario, the issues to be resolved or optimized (i.e. the
price of a material), and some confidential information that it is not known by the others
(their company negotiation position, ...). Accepting that role playing is the best choice to
improve negotiation skills, there is the need to test if the joint of this kind of games with a
quick theoretical knowledge on the principles of negotiation (ZOPA’s principles,
negotiation positions, kinds of negotiators, BATNA, etc.) would significantly improve the trainees’ results.

The main objective of the authors is to evaluate the adequacy of mixing playing sessions and theory to maximize the students’ negotiation skills. This is done thanks to a research carried out with students at the ETS of Industrial Engineers of the Technical University of Madrid (UPM).

To measure the natural skill’s improvement the students undergo when playing several times with a negotiation game, both with and without previous theoretical learning a predefined scoring system is used, combined with the time the negotiators spent to reach to the agreement.

The results will serve to introduce a short package of negotiation knowledge at post-grade engineering studies, as in the new educational programs some competences in Project Management are demanded.

**Role play planning**

Eleven teams were involved in the role play. Six teams will form the Experimental Group (EG) and five will be used as Control Group (CG). Both groups were asked to participate three times in a negotiation role play related to the construction project presented. After the first play, the EG received a theoretical class (F) about principles of negotiation. The objective of this theoretical class was to proof if during the next games those students have developed better negotiation skills and were able to obtain better results during the negotiation.

At the end of each game a survey was filled by each student with questions regarding the results of the negotiation, perception of the difficulty to reach the agreement, perception on the negotiators and general satisfaction with the agreement.

During the introduction of the course the frame of the negotiation was explained and the skills and qualities that a good negotiator needs. Several aspects were remarked:

a) The need to prepare properly. The difference between an interest and a position and why it’s important to separate them is highlighted.

b) Different roles played during the negotiation were explained.

c) The strategy must be created and will cover the entire negotiation.

d) A tactic, on the other hand, is a very important component within that strategy. Different negotiation tactics were presented during the course.
Figure 3. Methodology used to evaluate the improvement of both experimental group and control group

**Role play sceneries**

In this negotiation game each team is formed by three participants playing different roles (Agent A, B and C), with a different degree of complexity. The game is played three different times changing the conditions and doing the ZOPA smaller so the negotiation is going "harder". Each scenario created had a smaller ZOPA so it was more difficult for the team to achieve an agreement. Table 1 shows the data information of the different scenarios for negotiation per day.

**Table 1. Role play negotiation scenery. Offer for a bridge construction that needs the participation of two subcontractors**

<table>
<thead>
<tr>
<th></th>
<th>DAY 1</th>
<th>DAY 2</th>
<th>DAY 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AGENT A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bid price limit</td>
<td>250,000 € total</td>
<td>240,000 € total</td>
<td>250,000 € total</td>
</tr>
<tr>
<td></td>
<td>100,000 € fixed cost</td>
<td>100,000 € fixed cost</td>
<td>100,000 € fixed cost</td>
</tr>
<tr>
<td>Delivery time</td>
<td>65 days</td>
<td>61 days</td>
<td>58 days</td>
</tr>
<tr>
<td>Bonus for objectives</td>
<td>Reduction on delivery time, offer increases 600 €/day</td>
<td>Reduction on delivery time, offer increases 550 €/day</td>
<td>Reduction on delivery time, offer increases 500 €/day</td>
</tr>
<tr>
<td></td>
<td>Agent will increase the bonus 20% of offer increment</td>
<td>Agent will increase the bonus 20% of offer increment</td>
<td>Agent will increase the bonus 20% of offer increment</td>
</tr>
<tr>
<td>Constraints</td>
<td>Restrictions on storing cast girders</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 days for girder assembly</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AGENT B</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Job order</td>
<td>100 IPN 1000 girders</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offer price</td>
<td>5 girders/day 700 €</td>
<td>5 girders/day 700 €</td>
<td>5 girders/day 700 €</td>
</tr>
<tr>
<td></td>
<td>2 extra/day and weekends</td>
<td>2 extra/day and Saturdays</td>
<td>2 extra/day and Saturdays</td>
</tr>
<tr>
<td></td>
<td>770 € Subcontracted girder 1,800 €</td>
<td>770 € Subcontracted girder 1,600 €</td>
<td>770 € Subcontracted girder 1,200 €</td>
</tr>
<tr>
<td>Bonus for objectives</td>
<td>Agent will increase the bonus 10% of offer increment</td>
<td>Agent will increase the bonus 10% of offer increment</td>
<td>Agent will increase the bonus 10% of offer increment</td>
</tr>
<tr>
<td>Constraints</td>
<td>Storage of casted girders</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AGENT C</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Job order</td>
<td>1,000 m³ of concrete</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offer price</td>
<td>150 m³/day 40 €</td>
<td>135 m³/day 40 €</td>
<td>125 m³/day 40 €</td>
</tr>
<tr>
<td></td>
<td>250 m³/day 55 €</td>
<td>250 m³/day 55 €</td>
<td>250 m³/day 55 €</td>
</tr>
<tr>
<td></td>
<td>125 m³/day 60 €</td>
<td>250 m³/day 60 €</td>
<td>250 m³/day 60 €</td>
</tr>
<tr>
<td>Bonus for objectives</td>
<td>Agent will increase the bonus 5% of offer increment</td>
<td>Agent will increase the bonus 5% of offer increment</td>
<td>Agent will increase the bonus 5% of offer increment</td>
</tr>
<tr>
<td>Constraints</td>
<td>Product with only 1:30 hour delivery time</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It can be observed in Figure 2 how the ZOPA has changed through the different scenarios. In the figures the variations per day in the production cost is shown. As it was planned
Agent C has an easier price-time range, being day 2 and 3 very similar. Agent B risk of being the responsible of not closing an agreement is higher day 1 than day 3 (the slope of the production cost line is higher so a mistake in day of delivery will make difficult for the other agents to get an offer). Day 3 is the hardest scenario for Agent A to close negotiation since it has a range of only a few days.

![Graphs showing ZOPA for each agent at scenario 1, 2 and 3.](image)

Figure 2. ZOPA for each agent at scenario 1, 2 and 3

**Results and discussion**

**Results of the bid price and delivery time**

Even though at least four iterations were needed to reach an agreement, only final results will be presented. The single observation of the data shows that if one individual agent has a profit higher than 50%, the agreement will not be valid. There is a change from day 1 to day 3 where individual profit is more controlled. Even though neither day 1, 2 or 3 the totality of teams were able to reach a valid agreement, approaches are better day by day. The first day 3 groups were not able to reach an agreement; the third day two groups were not able to reach agreement. Small mistakes were made on day 3 for not considering the dates properly.

In order to better observe the general results, Figure 4 plots the individuals bid values. In the plots upper limit represents the best agreement while lower limit represents worst agreement per agent. A clear evolution, between day 1 and 3 can be observed since bids prices are closer to average and in between best and average agreement.
Teams that received theoretical class were 2, 3, 5, 6, 8 and 9

Figure 4. Negotiation bid prices

Figure 5 shows the profit distribution. It can be first observed that day 1 all agents have a high variability of benefit what makes a direct relationship with the difficulty to close a fair negotiation. Day 3 agent A for all teams has a very close benefit and agents B and C make a profit between 4% and 16%. Since in the plots all results are represented together there is no indication of teams that have received theoretic formation and those within. All together there is indication that the experience gained by playing will improve negotiation skills.

Teams results that were not able to reach a valid agreement are not plotted in Figure 6. Evolution from day 2 to day 3 in the number of teams that were able to close a good negotiation is better for the teams with theoretical knowledge. It is important to point out that the teams selected for receiving the classes were those ones with no so good results the first day, so the teams with poor previous skills for negotiation. However final results are very similar or even better.

Figure 5. Effect of theoretical knowledge on negotiation results
It can be observed that the evolution by experience is to get a more homogeneous benefit distribution. Students playing the role of Agent A learned their difficulty was in setting the time delivery and that they did not have much range for playing, so they have to get the better agreement for agent B and C; that's why their profit is slighter higher over 0%. Students playing the role of agent B also were able to get a more homogeneous distribution and what is more important is the evolution of those with the theoretical formation. Students playing the role C are the ones that day 3 played harder since they were able to get the higher individual profit.

**Results from the survey on negotiation skills**

Generally all students perceive smaller difficulty day 3 than day 1, even though scenario for day 1 was easier. It can as well be observed that students that have received some formation sense a smaller difficulty degree.

Students perceive a greater difficulty setting the bid price than delivery time, although both parameters are related, how can be checked in Figure 2. Students that have not received any theoretical training feel the same difficulty to fix the bid price day 3 than day 1; however students with theoretical training feel a perception of the difficulty lower. Teams with theoretical training not only sense a minor degree of difficulty but get better alternatives in bid prices.

After day 2 and 3, students were asked to answer a survey related to competences development through the game. Figure 6 show the results on the students' perception over the competence strengthen. The rectangular part of the plot extends from the lower quartile to the upper quartile, covering the centre half of each sample. The centre lines within each box show the location of the sample medians. The plus signs indicate the location of the sample means. The whiskers extend from the box to the minimum and maximum values in each sample, except for any outside or far outside points, which will be plotted separately.

![Figure 6. Competences development: Left, without training; Right with training](image)

Students without training perceive "leadership" and "management" the competences strengthened by the game. However students with theoretical training consider also "cooperation" as one of the competences with highest result.

**Conclusions and future developments**
In addition to detailed technical knowledge and performance skills in engineering education, other personal and contextual skills (like negotiation) are important for these students and requires engagement, communication, creativity, understanding, conflict resolution and decision making. The opportunity to develop these skills often is unavailable to students until they become employed. Introducing students to such experiences earlier can foster the development of these abilities.

This experience has demonstrated that learning by playing is an effective way to make student learning in the subject area of negotiation and it can be an important tool for improving engineering student performance as well as motivating and enhancing other non-technical abilities. The combination of playing and training has verified that the students with no special good negotiation skills at the beginning of the experiment have even reached better final results that those ones with natural negotiation skills.

The perception of both the students and teachers is that the learning approach tested was valuable and more productive than only lecture-oriented approaches, despite the fact that it required greater effort than the classical method. This experience would be adapted to other courses by changing the specific area like complaints and suppliers management. Our immediate plan is to complete the experiment by developing more personal and contextual skills for engineers: leadership, results-oriented and ethics among others. Also, scalability characteristics will be analysed by running the approach with nearly two hundred students.

References


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Shifting conceptions of engineering design: Longitudinal and cross-sectional studies of undergraduate engineering majors

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Abstract: Design is widely recognized as a central topic in engineering education, but we are only beginning to understand student conceptions of engineering design. Based on two survey data sets from the Center for the Advancement for Engineering Education’s Academic Pathways Study (APS), we provide a quantitative characterization of how student conceptions of engineering design change during the course of four years of undergraduate study, as well as a gender comparison of first-year conceptions of engineering design. As a secondary contribution, we discuss the two APS data sets as a case study in the methodological trade-offs between longitudinal and cross-sectional research designs. We found remarkable alignment between the two data sets, in spite of differences in data collection—one collected longitudinally and the other, cross-sectionally. The paper closes by discussing next analysis steps, as well as potential implications of our findings on how we educate undergraduate engineers.

Introduction

Design cuts a wide swath through engineering education curricula. Cornerstone and capstone courses use design to introduce and to facilitate synthesis of engineering content knowledge. Taking a learner-centered perspective, this paper provides a quantitative description of undergraduate students’ development as engineers via the ways their conceptions of engineering design change over time and vary by gender. The research questions are as follows: (RQ1) How do engineering undergraduates’ conceptions of design change during the course of four years of study? and (RQ2) How do engineering undergraduates’ conceptions of design vary with gender?

Based on two survey data sets from the Center for the Advancement of Engineering Education’s Academic Pathways Study, the focus is on those students who reported intention to major in engineering. Both sets consist of data from first- through senior-year
students, but one is matched longitudinal, with data from four annually administered surveys, and the other is cross-sectional, with data from one-time data collection across class standing (Hilton & Patrick, 1970). Our secondary contribution is methodological and concerns the extent to which a cross-sectional, quantitative research design can approximate an analogous longitudinal study of undergraduate conceptions of design. Hilton and Patrick (1970) have shown this may be possible under the right conditions, which we attempt to illustrate with our data.

**Theoretical framing and prior work**

Understanding the words engineers use to define and engage in design is a key part of engineering students’ intellectual and professional development. In terms of Lave and Wenger’s theories concerning social learning systems (Wenger, 2000) and communities of practice (Lave & Wenger, 1991; Wenger, 1998), the language of engineering design is an important component of the “shared repertoire” that is produced by engineers and defines them as a community. In this sense, by identifying the words and phrases that engineering students associate with design, we can gain insights into their learning and development as engineers.

The methodological component of this work can be understood in terms of the notion of triangulation, or the corroboration of findings through multiple research approaches. As commonly invoked in descriptions of mixed-methods research, triangulation refers to the use of distinct methods (e.g., survey and observation) in service of a common research question. In our case, the method is the same (survey), but we employ time triangulation (Cohen, Manion, & Morrison, 2005) to collect data from similar samples in two different ways: longitudinally and cross-sectionally. Hilton and Patrick (1970) provide a detailed discussion of trade-offs between longitudinal and cross-sectional approaches. Given the extensive time and resources required for longitudinal research, a thoughtfully designed crosssectional equivalent, if feasible and appropriate, would be an attractive alternative.

Substantial prior work in design education focuses on prescriptive, structured design methods (e.g., Pahl & Beitz, 1984). This work is complemented by broader, empirical studies like that of Capobianco et al. (2011), who captured elementary students’ conceptions and perceptions of engineering via drawing tasks. Lande and Leifer (2009) collected similar information from graduate students to better understand their conceptions of engineering and design. This paper builds on a longstanding body of work based on a multi-part survey item called the Most Important Design Activities (MIDA) question (Mosborg et al., 2005). The MIDA question asks respondents to select the six most important design activities from a list of 23 items, listed in Table 1. Prior MIDA-based research has compared undergraduate engineering students’ conceptions of design to those of professional engineers (Atman, Kilgore, & McKenna, 2008), examined gender differences in conceptions of design (Chachra et al., 2008), and studied the impact of a human-centered design course on conceptions of design (Oehlberg & Agogino, 2011).
Methods

Our analysis focused on two multi-institution data sets collected in the U.S. as part of the Center for the Advancement of Engineering Education’s Academic Pathways Study (Atman et al., 2010). Both data sets were from web-based surveys of first-year, sophomore, junior, and senior undergraduates, with women oversampled. We limited analysis to the students meeting two criteria: intention to major in engineering and valid MIDA responses. As part of the Persistence in Engineering (PIE) survey (Eriş et al., 2010), the first data set was collected longitudinally each spring from 2004 through 2007 from a total of approximately 160 undergraduates at four institutions: a public research university devoted to engineering and applied science; a comprehensive, historically Black, private university; a private research university; and a large, public research university. Among the students who were surveyed in all four years, 81 (38% women) met our selection criteria for analysis. The second data set was collected cross-sectionally in early spring of 2008 from a total of over 4,200 students at 21 varying institutions as part of the Academic Pathways of People Learning Engineering Survey (APPLES; Sheppard et al., 2010). Among these students, 809 first-years, 825 sophomores, 963 juniors, and 792 seniors (varying between 30% and 37% women) met our selection criteria for analysis. Statistical analyses of gender differences employed Fisher’s exact test. See the Atman et al. and Sheppard et al. reports for other methods details.

Findings

To address RQ1, for each of the 23 design activities, we examined the percentage of first-year through senior engineering students who selected that activity among their set of six most important (Table 1). The sparklines (Tufte, 2006) in the table’s “Data” columns show the four-year sequence of percentages, accompanied with coarse characterizations of the trends to the right. Activities that were less likely to be selected by upper-level undergraduates were Building, Imagining, Using creativity, and Visualizing. Those that were more likely to be selected include Identifying constraints, Iterating, Modeling, and Prototyping. These findings were observed in both the longitudinal and cross-sectional samples. Characterizations of four-year trends matched across the two samples for a substantial majority of activities (18 of the 23).

Extending prior analyses of the longitudinal sample (Chachra et al., 2008), we limited initial gender comparisons for RQ2 to first-year students. Table 2 shows only those design activities for which we observed statistically significant gender differences in the percentage of women and men selecting the activity in either or both of the study designs (longitudinal and cross-sectional). With the possible exception of Imagining, gender differences in the smaller, longitudinal sample were mirrored (and often more pronounced) in the cross-sectional sample. Women tended to favor activities like Communicating and Understanding the problem, while men tended to favor Building and Prototyping. The magnitudes of these relative differences are indicated in Figure 1, which also highlights an exception: the large gender difference in Seeking information that was observed in the longitudinal sample is absent in the cross-sectional data.
Table 1: Four-year trends in percentage of students selecting each design activity in longitudinal (N = 81) and cross-sectional studies (N = 792–963, depending on class standing). For trend characterizations, "-" signifies ambiguous or no change. Design activities are sorted by trend.

<table>
<thead>
<tr>
<th>Design activity</th>
<th>Data</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifying constraints</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iterating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Making trade-offs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modeling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prototyping</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generating alternatives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understanding the problem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abstracting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brainstorming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decomposing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goal setting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Making decisions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeking information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sketching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synthesizing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Testing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communicating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imagining</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using creativity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visualizing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Subset of design activities with gender differences in the percentage of first-years selecting each activity in longitudinal and/or cross-sectional studies (*p < 0.05, **p < 0.01, ***p < 0.001, ?p ≥ 0.05). Activities are sorted by direction and significance of gender difference.

<table>
<thead>
<tr>
<th>Design activity</th>
<th>Longitudinal</th>
<th>Cross-sectional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>M &gt; F*</td>
<td>M &gt; F**</td>
</tr>
<tr>
<td>Prototyping</td>
<td>M &gt; F*</td>
<td>M &gt; F**</td>
</tr>
<tr>
<td>Abstracting</td>
<td>M &gt; F?</td>
<td>M &gt; F***</td>
</tr>
<tr>
<td>Decomposing</td>
<td>M &gt; F?</td>
<td>M &gt; F*</td>
</tr>
<tr>
<td>Testing</td>
<td>M &gt; F?</td>
<td>M &gt; F*</td>
</tr>
<tr>
<td>Visualizing</td>
<td>M &gt; F?</td>
<td>M &gt; F*</td>
</tr>
<tr>
<td>Imagining</td>
<td>F &gt; M?</td>
<td>M &gt; F**</td>
</tr>
<tr>
<td>Seeking information</td>
<td>F &gt; M*</td>
<td>F &gt; M?</td>
</tr>
<tr>
<td>Communicating</td>
<td>F &gt; M?</td>
<td>F &gt; M**</td>
</tr>
<tr>
<td>Understanding the problem</td>
<td>F &gt; M?</td>
<td>F &gt; M***</td>
</tr>
</tbody>
</table>

Figure 1: Percentage of female and male first-years in the longitudinal (top) and cross-sectional (bottom) studies who selected each design activity (N = 81 and 809, respectively; *p < 0.05, **p < 0.01, ***p < 0.001).
Discussion

Analyses of the larger cross-sectional data set replicated earlier findings based only on the smaller longitudinal data set with respect to both change between first and senior years (Atman, Kilgore, & McKenna, 2008) and gender differences (Chachra et al., 2008). We saw evidence of acquisition of engineering-specific language (e.g., “identifying constraints,” “iterating,” “prototyping”), as well as gender differences that suggest that increased demographic diversity in engineering would bring diversity in design approaches to the table. Based on the data, we might informally characterize women as tending toward “design by understanding,” while men tend toward “design by building.”

In spite of differences between the two data sets, we observed remarkable similarity in both the fouryear trends and gender differences in conceptions of design as measured by the MIDA question. In the longitudinal data set, we are confident that most if not all students in the sample of 81 completed engineering degrees, because they reported their intention to do so in all four years of surveying. In contrast, in the cross-sectional sample, we are unable to know how many of those students who reported their intention to complete engineering degrees actually did so. As a result, especially in the first-year subsample, the cross-sectional data set probably includes students who eventually switched to a non-engineering major or even dropped out of school altogether.

Beyond differences associated with the longitudinal and cross-sectional nature of the data sets, although both data sets were collected from engineering undergraduates in the U.S., the longitudinal set was much smaller, collected at far fewer institutions, and differed in distribution across engineering subdisciplines. Alignment between the data sets in spite of these differences speaks to the robustness of the findings and is consistent with replication of other findings between PIE and APPLES (Eriş et al., 2010). With respect to future MIDA-based research, the alignment also suggests that a less resource-intensive and significantly more expedient cross-sectional approach might reasonably approximate an analogous matched longitudinal study. The validity of the approximation depends in part on assumptions that retest effect and selection effect (Hilton & Patrick, 1970) were negligible in our longitudinal study. Retest or practice effect seems unlikely, in the absence of a “correct” answer to the MIDA question and with the question having been administered only once a year. Selection effect was limited by surveying via web, giving students some flexibility with timing of participation.

Implications and future work

As has been done with other design research (Borgford-Parnell et al., 2010), the MIDA question and associated research can have immediate impact in classrooms and outreach settings by facilitating student discussions that reflect on design process and approaches. By studying findings like those presented in this paper, students could benefit greatly by becoming more aware of their own design approaches and by recognizing how they differ from other students’ approaches, all while acquiring a common vocabulary for discussing design in more precise terms.
With respect to other intersections between our research and educational practice, the changes and gender differences we observed raise questions of what factors and experiences influence how students conceive of design. How is the development of notions of design affected by individual characteristics and exposure to design-related experiences, both inside and outside the classroom? For example, it would be of interest to explore how involvement in extracurricular design activities may differ by gender (e.g., solar car and concrete canoe clubs, as well as engineering societies such as the Society of Women Engineers). Similarly, with respect to design-related curricula, particularly in introductory engineering design courses, further exploration of curricular content would be useful to benchmark how different approaches to design are privileged or legitimized.

As we examine in greater detail the developmental trends in design conceptions over the course of an undergraduate engineering career, we acknowledge a variety of ways in which we can refine and complement our statistical analyses. Although both data sets span multiple engineering majors, the distribution of students across majors is likely to differ. Preliminary comparisons of MIDA responses by major suggest some effect, implying the need to weight by major before comparing the two data sets. Other next steps include within-gender analyses of four-year changes in conceptions of design, as well as comparison with professional engineers’ conceptions of design. Finally, we anticipate that multi-method analyses including qualitative data such as design tasks (Kilgore et al., 2007) and interviews will illuminate connections between design learning and educational experiences, whether formal and curricular or otherwise. Depending on the nature of the research questions, qualitative methods and longitudinal study designs may still be preferable to and produce insights that are not possible with quantitative, cross-sectional study designs.

References


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Microgenres: Critical "markers" that can facilitate teaching and assessing writing within and across schools and colleges of engineering

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Abstract: This paper introduces the concept of microgenres and locates them within the well-established and now international field of genre studies. It describes a methodology for identifying microgenres and presents the promising early results of a preliminary study of one such microgenre, compositional report, extant in a corpus of student texts produced for a writing-intensive engineering course. These results indicate that microgenres can be identified in a way that is valid and reliable. They reveal that there is the possibility of variation or that there are ways of organizing this microgenre in order to realize purpose. These results also suggest that we might be able to construct a typology or typologies related to particular disciplines within engineering and/or the field of engineering, and thereby facilitate student learning, participation, and accessment.

Introduction

Over the last three decades, researchers from a range of different disciplines have begun to articulate an “understanding of genre that connects kinds of texts to kinds of social actions” (Bawarshi and Reiff, 2010). In other words, they have begun to explore specific genres as ways of getting things done or ways of doing something in particular. Whether we locate the origins of this understanding with Carolyn Miller (1994) and genre as “typified rhetorical and social action,” or with J.R. Martin (1985) and genre as “a staged, goal-oriented social process” or with John Swales (1990) and genre as “a conventionalized communicative event closely associated with communities of practice,” all represent important initial efforts in what has become known as the “generic perspective” (Bhatia, 2004). Indeed, that generic perspective today is emerging from five distinct although not dissimilar areas: Literary Theory, Systematic Functional Linguistics (SFL) or the Sydney School, English for Special/Academic Purposes (ESP/EAP), North American Genre Studies and Rhetorical Genre Studies (RGS) and the French and Swiss Genre Traditions and Brazilian Genre Synthesis (SDI) (Bawarshi and Reiff, 2010).

While each of these areas offers something special to our understanding of genre, they agree at least in general with Amy Devitt (2004), who defines genre as “typified action” in response to a “recurring situation,” an action that “commonly reveals its social functions with characteristic discourse features.” In addition, they agree that a certain genre “usually operates [within] a set of genres” reflective of “the values [and] epistemology” of particular “communities, collectives [or] social networks” (Devitt, 2004). And finally, they encourage that we adopt “genre awareness” as a teaching/learning outcome and believe that that outcome is best realized through “pedagogical strategies that keep generic form and generic contexts [and thereby actions] united” (Devitt, 2004).
Undergraduate writing/communication instruction in engineering (when it is provided at all) is most often offered through distinct writing/communication courses. These courses are typically taught either by departments outside of engineering or by writing/communication specialists within engineering, but who, themselves, are not engineers. And, while these courses focus on that collection of genres most apparent in the table of contents of any technical writing/communication textbook – proposals, progress and technical reports, journal articles, instructions, manuals, and so on – those genres when they are taught in either of these ways can have the effect of separating generic form from generic context. If students’ do not experience genres as contextualized social action and understand that action as enacted through form within a particular context, then their performance of those genres in those courses becomes little more than an exercise in which they are asked to demonstrate mastery of their writing/communication skills, those so-called “soft-skills,” that they (and even some engineering faculty) believe are apart from, not a part of engineering. Apparent in survey after survey of all the relevant stakeholders, the inevitable result is that there is a “large gap between the workplace needs and engineering graduates’ communication skills” (Reave, 2004).

The significance of this emerging understanding of genre is that it identifies the above genres as context-bound or situation-specific actions whose structure and particular linguistic features are inextricably linked. Further, it argues that because those genres are context-bound or situation-specific, they are integral to professional participation in the engineering community and, in fact, reveal that community’s values and epistemology. And finally, it suggests that genre awareness or a “raised consciousness” of structure and linguistic features and their relation to action(s) will facilitate learning and holds the most promise for enabling students-soon-to-be-professionals to continue to learn how to write/communicate in all the new and differently nuanced situations and/or contexts in which they will find themselves (Bawarshi and Reiff, 2010).

An explicit focus on developing genre awareness in writing/communication instruction has long been a particular emphasis of SFL or the Sydney School. Indeed, proponents believe that it is critical to make visible to “students the structural and linguistic features of genres, and how these features are connected to social function” (Bawarshi and Reiff, 2010). In their attempt to make structural and linguistic features more visible, Martin and Rose (2008) especially have researched that set of genres most often associated with particular disciplines and/or fields – history and science. They refer to this collection of genres or genre sets (like those listed above in relation to a technical writing/communication textbook) as “macrogenres” (Martin and Rose, 2008).

Further and specifically in relation to science, they claim that these macrogenres may actually be made up of a number of microgenres or more “elemental genres” or “short genres” such as descriptive, classifying, and compositional reports; sequential, consequential, and conditional explanations; various kinds of procedures – operating, conditional, and technical – and procedural recounts (Christie, 2002; Martin and Rose, 2008). It is the presence of these microgenres as important markers that give macrogenres, those larger genre sets associated with a discipline and/or field, their identity (Coutinho and Miranda, 2010). For example, most methods sections in
experimental science journal articles include at least two of the microgenres listed above: a compositional report or a description of the experimental apparatus and materials; and a procedural recount or a presentation through time of the experimental process. Martin and Rose (2008) claim that access to macrogenres, and perhaps even more importantly then to microgenres, plays a crucial role in the ability of professionals and students-soon-to-be-professionals to participate in disciplinary and/or field culture. Shown below in the reproduced Figure 4.23, they have even attempted to create something of a typology of microgenres in relation to science (they have done the same in relation to history) in order to facilitate not only the careful investigation of them as “interdependent and linked constituent parts” contained within those larger genre sets, but to enable access and through access authentic participation (Martin and Rose, 2008).

Figura 1: A typological perspective on relations between genres in science

**Method**

Within an academic/educational context, there are two general stages associated with discourse studies that attempt to identify the “complex interplay between texts and their social contexts” (Bawarshi and Reiff, 2010). The first stage is to investigate these texts within their contexts in order to gain greater understanding. There are four steps related to that investigation. The first is “to develop the analytical framework, determining the set of possible discourse unit types based on an a priori determination of the major communicative functions that discourse units can serve” in a select corpus of texts (Biber et al., 2007). The second is to “ensure that the corpus [of texts] chosen for analysis actually represents the discourse domain being studied” and can offer answers to the research questions being investigated (Biber et al., 2007). The third is to apply that framework in order to determine if we can “segment texts into discourse units” (Biber et al., 2007). And, if we can segment texts into discourse units, then the fourth is “to describe their linguistic characteristics” or their structure and linguistic features (Biber et al., 2007). These steps are not simply sequential, rather they are highly recursive. The second stage, if suitable, is
to find ways to apply that greater understanding in order to enhance teaching and learning and support assessment. Within the second stage, researchers (who are also teachers) attempt to develop a pedagogical approach that again enables greater access and participation as well as supporting assessment. One example of such a pedagogical approach that has developed from the investigations conducted within SFL is the "teaching-learning cycle" and its adaptations (see Macken et al., 1993; Hammond et al., 1992; Rothery, 1996; and Feez and Joyce, 1998).

In cooperation with faculty in the department of Biological and Environmental Engineering, select faculty in the department of Applied Engineering and Physics (AEP), and faculty teaching courses that require writing in other departments in the College of Engineering at Cornell University, I will begin in the fall of 2011 a two-year long investigation into the occurrence and schematic structure of microgenres in examples of student writing. My analytical framework in general is the empirical research on genre or the "systematic observation of genres within their settings of use" (Bawarshi and Reiff, 2010). More specifically, I am using SFL work with genres in order to explore a possible set of discourse units or microgenres and the functions they serve within their genre sets. Next, I am attempting to collect (actually create) a corpus that is both focused and yet diverse. The corpus is focused in that I hope to be able to concentrate my collection efforts across a range of courses in the department of Biological and Environmental Engineering. The corpus is diverse in that I have been and hope to continue to collect sample texts from a number of other courses in other departments across the College of Engineering – in particular the department of Applied Engineering and Physics.

There are two specific research questions that I expect to answer as I collect (create) this corpus. These research questions are related to the third and fourth steps of the initial investigative stage described above. First, given the apparent variability and mutability of the larger genres across these different fields of engineering, can I identify distinct microgenres in a way that is both valid, i.e., each exhibiting a recurring structure, and reliable, i.e., a structure that remains consistent within examples within a range of different, more traditional genres and across different disciplines within engineering? In other words, can I segment traditional genres into microgenres? And second, if I can identify microgenres in a way that is both valid and reliable, that describe their structure and linguistic characteristics or complete the fourth step, can I then identify enough of these microgenres to create a typology – perhaps a typology related to a certain discipline, perhaps a typology generally related to the field of engineering – similar to the one represented above? If I can create such a typology, then I can begin the second stage of my study: Begin to develop a pedagogical approach that might improve access, enable greater participation, and allow for assessment.

One of the potential outcomes of the research that I am proposing is the creation of a similar typology or typologies related to particular disciplines within engineering and/or the field of engineering with the similar effects of facilitating investigation and enabling the access and participation of engineering students.
Preliminary (but exciting) Results

Discourse studies of this nature are often referred to as representing a “top-down approach,” and, because they involve a careful reading of a large number of texts within a corpus, are considered “highly labor intensive” (Biber et al., 2007). In order to ensure the potential for valid and reliable results, results that can make a significant teaching/learning impact, I have been engaging in preliminary research for last two years involving a number of writing-intensive engineering courses. These are courses within the engineering curriculum that require writing and usually a lot of it. Because of pilot-nature of my results so far and because of the constraints of time (and space) in this paper, I want to focus on one course, entitled Computer-Instrumentation Design, offered in the department of Applied Engineering and Physics.

Referring back to Figure 4.23 above, there are three types of reports or examples of microgenres that Martin and Rose (2008) believe are typical in science: a descriptive report, a classifying report, and a compositional report. Each of these reports serves a different purpose or function, each does something in particular. Descriptive reports “classify and describe phenomenon;” “classifying reports subclassify members of a general class;” and “compositional reports are concerned with . . . parts of wholes” (Martin and Rose, 2008). Because at least some of the writing of undergraduate engineering students (especially writing that follows laboratory research) requires that they describe the apparatus and/or materials they use to conduct their research, I was drawn generally to reports and specifically to compositional reports. Again in Computer-Instrumentation Design, undergraduate engineering students are asked to produce four traditional genres: a rapid communication (mini-article), a recommendation report, a progress report, and an informational/analytical report. In order to conduct the research necessary to produce those traditional genres, students used various apparatuses in a laboratory to generate data for analysis. In response to my first research question, I analyzed three different traditional genres, a rapid communication, a recommendation report, and a progress report. That analysis took place over two years and included a corpus of approximately 140-145 texts composed by 45-50 writing teams. My goal was to determine if I could identify the compositional report, one microgenre, in all three of the traditional genres.

Given the analytical framework, there are two predominate methods for identifying distinct microgenres in ways that might be considered valid and reliable – move analysis and schematic analysis. Move analysis originated with John Swales (1990, 2004) and attempts to describe “a sequence of ‘moves,’ where each move represents a stretch of text serving a particular communicative function” (Biber et al., 2007). Similarly, schematic analysis “simply refers to the staged, step-by-step organization of a genre” that allows it to accomplish its purpose (Eggins, 2004). Clearly, both methods describe a sequence or a step-by-step organization. I chose to use schematic analysis because, especially in relation to microgenres, it offers a more compact description of the entire generic structure – a very formula-like representation – that would better serve determining if microgenres exhibit a recurring structure that is consistent across a range of examples.
Perhaps the most accessible analogy for performing a schematic analysis and the resulting representation of that analysis is that of diagramming a sentence. When we diagram a sentence, we typically separate out the various constituent parts, e.g. subject, verb, object, and represent them in a way that suggests their relation, interdependency, e.g. agent, action, entity affected by the action. Similarly, when one does a schematic analysis or specifically, in my case, when I did a schematic analysis attempting to identify the constituent parts of a compositional report, I discovered the four listed below.

**Constituent List of a Compositional Report**

- Label of Whole
- Identification of Part/Activity/Location/Relation
- Elaboration of Part/Activity/Location/Relation
- Description of Action in the Experimental Process

In other words, all the texts that made up my corpus included the microgenre of the compositional report. Further, each of those compositional reports included at least the top three of the four constituent parts. In addition, I discovered that there were two structures that revealed the relation, interdependency of these constituent parts. Those two schematic structures are represented below.

**First Schematic Structure of a Compositional Report**

Labeling of Whole ^ < {Identification of Part (* Activity * Location * Relation) ^ Elaboration of Part (* Activity * Location * Relation)} >

**Second Schematic Structure of a Compositional Report**

Labeling of Whole ^ < {Identification of Part (Activity * Location * Relation) ^ Elaboration of Part (Activity * Location * Relation)} >^ < Description of First Action in the Experimental Process ^ Description of the Second Action in the Experimental Process ^ and so on}>]

In Appendix A, I have provided two sample compositional reports and the linear descriptions of their schematic structures. And in Appendix B, I have provided a legend for readers unfamiliar with symbols used to represent the above schematic structures.

These results are exciting for a number of reasons. Perhaps the way that they are most exciting is that they suggest that we can identify microgenres within a particular corpus of texts in ways that are valid, exhibit recurring structures; and that reliable, structures that remain consistent within and across a range of different, more traditional genres. In other words, this analysis shows that we can identify the constituent parts of a microgenre and the step-by-step organization or relation, interdependency of those constituent parts. In addition, these results reveal that there is the possibility of variation or that there are at least with a compositional report two possible ways of organizing those constituent parts. The possibility of variation allows for creating a better fit for the relation of form and function. A certain formal representation may and probably does facilitate performing some action or doing something in particular. Finally, identifying a certain microgenre, its constituent parts and their relation, identifying the possibility of variation presumably for
the purpose of performing some action in particular is suggestive that continued research of this nature might enable us to identify other microgenres and their possibilities of creating form in order to realize function. Indeed, we might be able to construct a typology or typologies related to particular disciplines within engineering and/or the field of engineering.

**Implications for Teaching and Learning Writing/Communication in Engineering**

My intention in the opening of this paper was to suggest that language theorists from a range of disciplines now have a fairly unified understanding of genres or at least an appreciation for the relatively nuanced differences between our various understandings of genres. However, answering the question of how to facilitate the teaching and learning of disciplinary genres is extremely complex. According to Christine Tardy (2009),

“Learning . . . genres goes beyond learning form. Students must learn the discursive practices of their discipline, including the preferred ways of constructing and distributing knowledge, the shared content knowledge, and the intertextual links that build such knowledge . . . they must also develop a knowledge of the labels given to commonly used genres, the communicative purposes of different genres, the sociocultural context in which genres operate, the formal textual features associated with genres, and the cultural values embedded in genres. Individual success in this process is influenced by many individual, social, political, cultural and linguistic factors – all of which make the learning of ‘disciplinarity’ (and thus disciplinary genres) more time-consuming, difficult, and frustrating.”

If we are to realize genre awareness, practicality requires us to work toward a pedagogy that is responsive to these complexities. Yet that pedagogy must be generalizable beyond our stand-alone writing/communication courses, accessible to engineering faculty interested in teaching writing/communication, and useful in the study specific and demonstrable outcomes. Martin (2001), Christie (2002), Iedema (1997), and others within the “Sydney School” have identified microgenres in academic, instructional, even industrial contexts. If we can identify them in the samples of students' writing as they learn more traditional and disciplinary genres and disciplinarity, then we can help them see and understand the relation between those genres, microgenres, and that disciplinarity. Engineering faculty already can see and understand. However, introducing them to microgenres allows them to make explicit what for them has become tacit. It allows them to reclaim their own considerable genre knowing and doing in ways that enable them to share it with their students. Finally, creating a typology or typologies of microgenres not only organize our teaching, but can provide a systematic approach to assessment across the engineering curriculum. Assessment as we have come to understand it refers to the act of collecting data or evidence that can be used to answer classroom, curricular, or research questions. Clearly, microgenres, their relation to one another and “what they do” in traditional, disciplinary genres and how they can be used as data for learning outcomes make them extremely valuable.
References


Tardy, C.M. *Building genre knowledge: L2 writing*. West Lafayette, IN: Parlor Press.

**Appendix A**

**Sample Compositional Reports and their Linear Descriptions**

**Sample 1**

LabVIEW is a graphical programming environment, i.e. a program or virtual instrument (VI) is implemented via the construction of a visual representation of the desired function rather than through text-based code . . . . The main two VIs implemented in our project were RECORD.VI and PLAYBACK.VI. RECORD.VI allows the user to write a sequence of robotic arm positions to a text file. Figure 3 shows the front panel of the VI, which includes sliders that move each of the arm's servos across its full range of motion and a "record" button to save the arm's current position. The path for a file to which the recorded positions will be written is assigned in the "Name of the File to Record" box. Each operation on the front panel corresponds to a tool on the block diagram, shown in Figure 2. PLAYBACK.VI plays back a sequence of positions recorded in the file specified "File Name to Display" on the VI's front panel. The front panel for PLAYBACK.VI is shown in Figure 5. Other key elements of the front panel are displays of the current arm positions and the number of arm positions in the file.

**Linear Description of Schematic Structure**

Labeling of Whole ("LabVIEW") ^ Elaboration of Whole ("program or virtual instrument") ^ and Activity ("implemented") ^ Identification of Part ("RECORD.VI," PLAYBACK.VI") ^ Identification of Part ("RECORD.VI" and Activity ("allows to write") ^ Identification of Part ("robot arm") ^ Elaboration of Part ("the front panel of the VI, "sliders, “record button”) and Activity ("includes,” “move,” “save”) ^ Elaboration of Part ("path for a file") and Activity ("assigned") ^ Elaboration of Part ("operation of the front panel") and Activity ("corresponds") ^ Identification of Part ("PLAYBACK.VI") and Activity ("plays back") ^ Elaboration of Part ("other key elements," displays of the current arm positions," “number of arm positions in the file”).

**Sample 2**

Our Boltzmann Machine has two platforms at different levels (see Figure 1) to represent lower and higher energy states. The lower level has nine ping pong balls to represent gas molecules, and each level has a Squiggle Ball to represent randomness in the system. The platforms are bordered by elastic rings top prevent [the ping pong and] Squiggle Balls
from escaping . . . While still allowing the ping pong balls to move between levels. There is a smooth transition from the lower level to the higher level as shown in Figure 2 so that ping pong balls can easily roll between the levels.

We used three different levels, 0.25”, 0.5”, and 0.75”, and performed three trials for each level. For each trial, we placed a Squiggle Ball on each level and nine ping pong balls on the lower level. When we turned on the Squiggle Balls, we started video-recording the higher platform for five minutes. At the end of five minutes, we observed how many balls were on the higher level and placed the same number of balls at the beginning of the second trial. After the third trial, a total of fifteen minutes was recorded for a single level. With A4 Video Converter, we converted the video into a series of images and used the images on Matlab to determine how many of the ping pong balls were on the higher level for what period of time . . . .

Linear Description of Schematic Structure

Labeling of Whole (“Boltzmann Machine”) ^ Identification of Part (“two platforms”) and Location (different levels) ^ Elaboration of Part (“represent lower and higher energy states”) ^ Identification of Part (“nine ping pong balls”) and Location (“lower level”) ^ Elaboration of Part (“represent gas molecules”) ^ Identification of Part (“Squiggle Balls”) and Location (“each level”) ^ Elaboration of Part (represent randomness) ^ Identification of Part (“elastic rings”) and Location (“bordered”) and Activity (“prevent,” “allowing”) ^ Identification of Part (“smooth transition”) and Location (“from the lower level to the higher level”) ^ Identification of Part (“ping pong balls”) and Activity (“roll”) and Location (“between the levels”) ^ Description of the Actions in the Experimental Process (“used,” “performed,” “placed,” “turned on,” “started,” “observed,” “placed,” “converted,” “used,” “to determine”).

Appendix B

Symbols used to describe Schematic Structure

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>X ^ Y</td>
<td>stage X precedes stage Y (fixed order)</td>
</tr>
<tr>
<td>* Y</td>
<td>stage Y is an unordered stage</td>
</tr>
<tr>
<td>(X)</td>
<td>stage X is an optional stage</td>
</tr>
<tr>
<td>&lt;X&gt;</td>
<td>stage X is a recursive stage</td>
</tr>
<tr>
<td>&lt; { X ^ Y } &gt;</td>
<td>stage X and Y are both recursive in the fixed order of X then Y</td>
</tr>
</tbody>
</table>

(Reproduced from Eggins, 2004)
Observational research methods to explore intercultural competence in engineering

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Abstract: The Faculty of Engineering at the University of Wollongong has recently engaged in an Australian Learning and Teaching Council funded project to address issues of cultural diversity in engineering with a focus on the intercultural competence of first year engineering students and teaching staff. In the initial stages of this project, qualitative observational research techniques are being used to determine the current state, or baseline, of intercultural intelligence in first year engineering students.

This paper describes the observational research method developed for this research, issues encountered and overcome, and some preliminary findings. Observational reference points have been established to collect instances of group interactions, along with a paper based survey to identify instances of cross-cultural interaction and intercultural competence. In this research, students are video-recorded over the course of a normal project team meeting or tutorial class. Several groups of students are observed to ensure a range of cultural backgrounds are included in the research, and also to identify whether any differences in students’ approach to interacting with their teammates exist when obvious/anticipated differences in cultural backgrounds are present. Video recordings are being analysed using NVivo with the aid of observational reference points as research nodes.

While this research is a work in progress, early results point towards a quite uniform self perception of cultural awareness, despite instances of group tension observed in class. The results of this research will be fed forward into the redesign of learning activities intended to increase students’ awareness of their intercultural competence and group interactions.

Introduction

There is a difference between espoused views and values (those upon which people think their actions are based) and the frameworks they use to decide upon a course of action or the way they behave (Argyris & Schon, 1978). This is a noteworthy concern when
investigating intercultural competence in engineering, and will be revisited throughout the paper.

In 2010, the Faculty of Engineering at the University of Wollongong commenced a project to explore how to effectively address one of its stated graduate attributes, ‘respect for views, values and culture of others’. The significance of this particular graduate attribute statement is that it concerns the way that graduate engineers behave and respond towards others in a way that is often not obvious to individuals themselves. As a result, this involves behaviours that are not necessarily linked to explicit knowledge that can be ‘taught’ in a traditional manner. The phrase ‘respect for views, values and culture of others’ and the meaning drawn from it has been condensed here into the simpler and more broadly recognised term, ‘intercultural competence’.

How, then, do we observe, and on the grander scale, assess, intercultural competence when confronted with the challenge of espoused positions versus actions? The work presented here follows on from a pilot project described in (Goldfinch, Layton, & McCarthy, 2010), with further outcomes of this pilot study due to be published and presented elsewhere. In this paper, the authors describe the development and implementation of an observational research process designed to evaluate the current state of intercultural competence of first year students studying engineering. Some preliminary outcomes available at the time of writing are also presented, however the intent of this paper is primarily to present the process as a practical alternative to other qualitative methods such as focus groups, interviews, and stand alone questionnaire based surveys. The authors invite comment from the engineering education community and welcome collaboration with interested individuals.

**Theoretical frameworks**

When considering cultural issues as a focus of research, it is crucial to distinguish culture from nationality, and to avoid defining culture through social stereotypes. A recent definition of culture has it as a catch-all term representing influences from multiple sources, including the natural environment, ‘sociopolitical factors (e.g. sociocultural history, government and laws, religion, etc.) as well as familial and communal customs, norms, beliefs, opinions and rituals’ (Matsumoto, 2004, p. 276). Applying such a broad frame of reference to discussions on cultural issues helps to avoid assigning responsibility for behaviour and attitudes completely to a cultural group, or to the individual.

Thus, cultural definitions such as Masumoto’s help in understanding differences in the behaviour of individuals within a group, but do not necessarily help us to predict this behaviour due to inherent differences in individual aspirations, emotions and backgrounds, which may also be task and context dependent. Bales (1950) developed a framework for analysing interactions between individuals in a group, or team setting. The Interaction Process Analysis (IPA) framework has been widely applied in group observation research, particularly in multi cultural contexts (Lingham, Richley, & Serlavos, 2009; Nam, Lyons, Hwang, & Kim, 2009; Vallaster, 2005). The IPA framework, presented accessibly by Carney (1976, p. 160) is presented in Table 1.
Table 1: Bales Interaction Process Analysis

<table>
<thead>
<tr>
<th>Interaction type</th>
<th>Demonstrated behaviour</th>
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<tbody>
<tr>
<td>Group maintenance - Positive</td>
<td>1. Shows solidarity: raises other’s status, gives help, brings others in, praises</td>
</tr>
<tr>
<td></td>
<td>2. Releases tension: eases over difficulties, jokes, laughs, shows satisfaction</td>
</tr>
<tr>
<td></td>
<td>3. Agrees: accepts, understands, concurs</td>
</tr>
<tr>
<td>Task orientation – Positive</td>
<td>1. Gives ideas: suggests alternatives, outlines options, opens up horizons, non-directive</td>
</tr>
<tr>
<td></td>
<td>2. Gives evaluations: offers opinions, analyses; expresses feelings, wishes</td>
</tr>
<tr>
<td></td>
<td>3. Gives direction: clarifies, orients, informs, recalls, confirms, sums up, watches time</td>
</tr>
<tr>
<td>Task orientation – Negative</td>
<td>1. Asks for direction: clarification, orientation, information, repeats of information, summaries, prodigal of time</td>
</tr>
<tr>
<td></td>
<td>2. Asks for or challenges evaluations: questions analyses, assessments, feelings, opinions, wishes</td>
</tr>
<tr>
<td></td>
<td>3. Asks for ideas: indicates lacks alternatives, options, direction, possible ways of action</td>
</tr>
<tr>
<td>Group maintenance - Negative</td>
<td>1. Disagrees: silent disagreement, insists on formalities, withholds help</td>
</tr>
<tr>
<td></td>
<td>2. Contributes to tension: unhelpful, freeloads, shows discomfort, demands help, promotes misunderstanding</td>
</tr>
<tr>
<td></td>
<td>3. Shows antagonism: imputes motives, judges in value-laden terms, uses irony and sarcasm, plays power games, verbal dwelling</td>
</tr>
</tbody>
</table>

Bales IPA has its faults, in particular, the differentiation between positive and negative interactions can be interpreted as showing bias towards some Western cultures. However, the application of this framework to observation of group interaction provides a useful base to then compare against cultural differences evident in the group.

**Methodology**

The authors identified three components which must be considered in the research process. Firstly, how aware are students of their own intercultural competence? Secondly, how can we validate student’s self perception of their intercultural competence? Finally, how can we objectively identify any differences in intercultural competence amongst students?

Expressed attitudes, beliefs, intentions, norms, roles and values, all considered to be aspects of the self (Triandis, 1989), should reveal students’ self-perceptions of intercultural competence. However, as self-reported attitudes and values are relatively unstable and can be misleading (Heine, Lehman, & Peng, 2002), experimental and ethnographic evidence is needed. It is for this reason that focus in this study includes observing intercultural interactions in the classroom, in all of their complexity.

To address our three lead questions, a research method was developed that incorporated measures of self, peer and external evaluation, in a two-stage experimental process: an initial observation and inquiry as a baseline in semester 1, and a second round of observations/inquiries following our educational intervention in semester 2. The components of the measures used are clarified in figure 1.
In semester 1, a slightly modified cultural intelligence scale (Mini-CQS) (Ang & Van Dyne, 2008) was used as an identifier of students’ experience of, and self rated competence in, dealing with intercultural interactions. It was distributed to students at the conclusion of a preliminary observation session. Not wanting students to be overly conscious of their observed behaviour, the researchers framed the purpose of this part of the questionnaire in the context of an engineering design challenge that was to be undertaken in their second semester which involves developing an engineering solution for a developing community overseas (EWB, 2011). There are nine items on the Mini-CQS which are rated in terms of agreement with the statement on a scale of 1-7:

1. I frequently interact with people from different cultures
2. I am sure I could deal with the stresses of adjusting to a culture that is new to me
3. I know the cultural values and religious beliefs of other cultures
4. I know the legal and economic systems of other cultures
5. I know the rules (e.g., vocabulary, grammar) of other languages
6. I am conscious of the cultural knowledge I use when interacting with people with different cultural backgrounds.
7. I check the accuracy of my cultural knowledge as I interact with people from different cultures
8. I change my verbal behaviour (e.g., accent, tone) when a cross-cultural interaction requires it
9. I change my non-verbal behaviour when a cross-cultural situation requires it

Coupled with this are demographic questions on gender, educational background, and the type of area in which the individual grew up, i.e., urban, rural, or remote.
Moving on to peer evaluation, the questionnaire then asks students to rate interaction in their project group using the Tempelaar (2005) Tutorial Group Evaluation, which itself draws on the Bales IPA framework. Again using a rating scale of 1-7, students rate the common behaviour in their project group (normally three students) from ostensibly negative interactions (one) to positive interactions (seven), based on the behavioural indicators in Table 1. This peer evaluation of group interactions allows the researchers to triangulate their analysis of group interactions, by creating a bridge between self and external evaluations. Differences or similarities between how each group member views group interactions will aid the researchers understanding of the group dynamic when differing evaluations of interactions are observed.

The external evaluation of students’ behaviour is being conducted using video recordings of project groups working in a tutorial class setting (10 groups of 3 students per class), and in an out of class single project group setting. In all, 21 project groups have been involved in this first round of research, or 63 individual students.

In terms of data analysis, the video recordings are currently being analysed using NVivo 8 (a qualitative data analysis tool), with group interactions coded against the Bales IPA. Individual items within the Mini-CQS are being compare with each other to identify conflicting statements. For instance, students who indicate they change their verbal behaviour when interacting across cultures, but also indicate they are unfamiliar with the cultural values and religious beliefs of other cultures, may not be changing their behaviour appropriately or consciously.

Then, too, in validating self perceptions against observed behaviour, several items in the Mini-CQS lend themselves to external validation. Observation of students’ interactions within groups where one or more members have English as second language will be compared against their self ratings of items 5, 8 and 9. Once likely cultural differences within a group are identified, other Mini-CQS items will be compared against actual behaviour in the group setting. Individuals’ ratings on the Tempelaar (2005) Tutorial Group Evaluation scale will also be compared with observed behaviour to establish the likely reliability of students’ self ratings of behaviour.

The final question, ‘how can we objectively identify any differences in intercultural competencies amongst students?’, requires a second iteration of the process, after the educational interventions planned for semester 2. At this stage, students’ work will also be examined, to identify the extent to which they have been able to translate espoused views and values into the technical domain.

**Preliminary Results**

Preliminary results do indicate a high degree of consistency in ratings across Mini CQS and Tempelaar Tutorial Group Evaluation scales: students’ self and peer ratings coincide, and are skewed towards the positive. Taking into account the return rate of almost 100%, this outcome is contrasted against clear differences in the way individual groups interact within the same tutorial class setting in the video-recordings. Table 2 shows the degree of consistency across ratings in the tutorial group evaluation scale.
Table 2: Average ratings of table groups on Tempelaar Tutorial Group Evaluation scales

<table>
<thead>
<tr>
<th>Group Maintenance</th>
<th>Class 1</th>
<th>Class 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 1</td>
<td>1 2 3 4 5 6</td>
<td>Class Ave 1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>1</td>
<td>6.2 6.2 5.7 5.6 5.3 6</td>
<td>5.8 5.3 6.8 5 6.5 5.8 6 5.9</td>
</tr>
<tr>
<td>2</td>
<td>6.2 5.2 6 5.2 6.3 5</td>
<td>5.7 6.3 5.3 7 5.5 6.5 6 6.2</td>
</tr>
<tr>
<td>3</td>
<td>6 6.4 5.3 6 6 6</td>
<td>6 6.2 5.3 6.8 5.5 7 6 5.3 6.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Orientation</th>
<th>Class 1</th>
<th>Class 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 1</td>
<td>1 2 3 4 5 6</td>
<td>Class Ave 1 2 3 4 5 6 7</td>
</tr>
<tr>
<td>1</td>
<td>4.6 5.4 5.7 5 5.3 6</td>
<td>5.3 5.8 5 6.6 4.5 6.5 5.5 5.3 5.6</td>
</tr>
<tr>
<td>2</td>
<td>6.2 6.6 5.3 5.6 5 5</td>
<td>5.6 6 5.3 7 5 6.5 6.3 5.3 5.9</td>
</tr>
<tr>
<td>3</td>
<td>4.8 6.2 6 5.2 6.3 5</td>
<td>5.6 6 5.7 6.8 5.5 7 5.7 5.7 6.1</td>
</tr>
</tbody>
</table>

This would indicate that engineering students’ understanding of positive group interactions, and the intricacies of intercultural interaction, are inconsistent with their behaviours, and is consistent with research suggesting that subtle and unconscious behaviours maintain the status quo in intercultural contexts, particularly when people believe themselves to be egalitarian (Gaertner and Dovidio, 1986). Further analysis of the data collected is needed to confirm this preliminary indication, and to provide more detail on where particular inconsistencies lie. This work is currently underway, and the authors aim to present further research outcomes at the time of the conference.

Discussion

At this early stage in the research process, there are indications that the expected gap between espoused views and values and students’ behaviour is a significant issue for teachers in fostering the acquisition of intercultural competence. It remains to be seen whether the type of educational interventions we have already piloted, and which we are extending, will have an impact on students’ interpersonal behaviours or on their work.

At a more practical level, gaining informed consent from most students was not problematic for the two tutorial classes involved, however, the researchers experienced difficulty in recruiting students to take part in the individual group observations. This will be addressed in future sessions by offering extra tutorial assistance to participating groups as an incentive, rather than monetary incentives which proved expensive, yet unappealing to students. The paper based questionnaire will also be modified slightly to identify language barriers which may be influencing group interactions independently of significant cultural differences. No modifications are required in terms of recording group work; the researchers found that students worked easily in front of a video camera, and did not react to its presence once their activities were underway. With these revisions, the research will be duplicated at four other institutions in first and second year engineering courses.
Conclusion

In all, the researchers have found the video observation, coupled with the multifaceted questionnaire, has been an effective method of collecting rich research data. In analysing this data further, the researchers aim to establish a baseline for intercultural competence amongst first year engineering students to inform the development of learning activities for undergraduate engineering degree programmes. As part of the overall project exploring intercultural competence, packaged learning modules will be made freely available online in 2012 for others to test their usefulness in their own educational contexts.

References


Acknowledgements

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Does social capital matter? Impacts of social capital on African American male achievement

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Abstract: The engineering field has long been the last male stronghold with more than 80% of all engineering degrees being awarded to men in the United States. More recently, statistics have shown that the retention rate of Black male engineering students is only 40%, while their White peers have a 66% retention rate. With inequity of Black males enrolling and persisting in engineering it is essential to explore factors that may contribute to their retention and persistence to the bachelor’s degree. The present study provides a comprehensive account of 53 Black engineer students exploring the presence of social capital in engineering education and its effects on academic achievement and support for Black male engineering undergraduates using a mixed method approach. Quantitative and qualitative data were gathered from surveys, structured interviews, and focus. Data analysis for the project is still in progress. Preliminary analyses from student surveys are reported.

Background

More than 80% of all engineering degrees in the United States are awarded to men. However, the experiences of U.S. males in engineering are not all the same. Recent statistics show that the retention rate of Black male engineering students is only 40%, while their White peers have a 66% retention rate. These disparities among enrollment, retention and degree attainment between these populations directly translate to a lack of diversity in the US engineering workforce. This lack of diversity is not one to be taken lightly, as it impacts American society greatly through three distinct modes: Equity, Quantity and Quality (Wulf, 2002).

Throughout American higher education history, minorities have underachieved when compared to the majority. More specifically, the disparities are greatest between Black males and White males. This inequity exists in the form of lower enrollment rates, persistence, degree attainment and academic success. When compared to White men in
higher education, Black men enrollment rates are much lower, and their attrition rates are significantly higher in STEM (science, technology, engineering and mathematics) fields (National Science Foundation [NSF], 1995-2004). These discrepancies among this population stem from pervasive social and economic challenges, which one could undoubtedly say are unique to Black men in America. Research by Polite and Davis (1999) illustrates that this population of young people is often deprived access to college preparation activities and curriculum. Certainly, the evidence supports why the few Black males who complete secondary education are underprepared in higher education, and struggle to persist to attain degrees. The inequity present in this population directly corresponds to the lack of Black males entering STEM fields and, inevitably, leads to a lack of diversity in the workforce.

This issue of equity directly spills over into the issue of quantity. According to the US Census Bureau (2004), the number of minorities, including Blacks, is projected to increase significantly in the next 40 years. With the projected transformation in American demographics, minorities will then make up roughly half of the population. Additionally, the population of Whites is projected to decrease. Providing that the population transforms as projected, if the current rate of degree attainment for minorities is maintained, surely this will lead to a shortage of engineers. Therefore, at this point, the presence of minority engineers is crucial to the sustainability of the US engineering workforce, making it imperative that we focus on the persistence and retention of Black male engineers towards degree attainment. A third threat to the US engineering workforce, brought on by a lack of diversity is one of quality. Past president of the National Academy of Engineering (NAE), William Wulf (2002), posited that engineering quality is directly affected by a lack of diversity. Creativity, a crucial element in engineering design, is enhanced by the prior knowledge gained by the past experiences of the designer. The lack of diversity in engineering significantly diminishes the breadth of solutions that are considered for engineering problems. More so today, with the economy becoming more global, the same solutions that may have worked for and on a small population of similar people, will not work for a more diverse market. With the daunting statistics reflecting the inequity of Black males enrolling and persisting in engineering and the projected transformation of the US population, it is essential that researchers explore factors that may contribute to their retention and persistence to the bachelor’s degree.

Based on past research, one factor that holds great promise in increasing diversity in the engineering workforce is social capital. Social capital is the networks that are created and reproduced socially that serve as resources for individuals who in the absence of these networks would not be able to accomplish certain goals (Coleman, 1988). Coleman (1988) used social capital to describe the experiences of the working class and marginalized groups alike. Recent studies use social capital to examine retention and persistence in college students (Hinton & Adams, 2006; Palmer & Gasman, 2008). The theory of social capital can be applied directly to networks that students acquire before and throughout their higher education career.

In one study by Hinton and Adams (2006), it was found that Black high school students who were provided with high levels of social capital were more likely to be accepted into
college. The main source of social capital for students was the networks provided by their counselors for students to gain information, support and guidance regarding preparation and application to college. These networks are not only important for Black students on the high school level, but are also important throughout their years in higher education. Recently, Palmer and Gasman (2008) conducted a qualitative study where the role of social capital in promoting academic success for African American men at HBCUs was investigated. It was asserted that four elements were imperative to the functioning of social capital in the persistence and academic success of these students—faculty, administrators, peers and mentors.

Studies have shown that social capital “positively relates to academic success” (Palmer and Gasman, 2008) but few studies have explored these positive effects at a minority serving institution. Furthermore, no study to date has explored the effects of social capital on Black male engineering students in higher education as we are doing in this study. The goal of this study is to provide a comprehensive account of social capital in engineering education and its effects on academic achievement and support for Black male engineering undergraduates, one of the most underrepresented groups in the field of engineering.

Research Questions

We hypothesize that building on social capital is critical to enhancing the academic success of Black male engineering undergraduates and seek to address the following questions—

1. In what ways does social capital directly affect students’ academic achievement?
2. What forms of capital provide students with higher levels of academic support?
3. Are students with more reported social capital performing at higher levels in the engineering program than their counterparts with less reported capital?
4. What is the impact of the environment in which the capital is obtained?

Theoretical Framework

Social capital theory is a factor that has most recently been used to understand the persistence and retention of students. This theory was originally used by economists to describe class divisions. Bourdieu (1983) viewed social capital from a Marxist perspective, as an ‘attribute of the elites’. He saw social capital as a system of networks that were possessed by the elites that allowed them to gain an advantage as the dominant class. These networks were among the privileged and so helped them to maintain their status. However, Coleman (1988) used the functions of social capital to brew its definition. He viewed social capital as a compilation of entities that underpin social structures. Through these entities, the possibility of achieving certain goals, which would be nearly impossible if not for the presence of such structures, becomes a reality. Coleman (1988) describes three forms of social capital: obligations and expectations, information channels, and social norms.

The first form of social capital, obligations and expectations, is the process in which individuals in the social network do for one another, or help each other (Coleman, 1988). The second form of social capital, information channels, is the process by which
information which might be costly or almost impossible to receive is transferred by means of social relations (Coleman, 1988). This speaks to being able to use others as sources of information. However, certain types of information also extremely useful are privileged and are more likely to be shared exclusively among individuals within the same social circles (Coleman, 1988). The last form of social capital, social norms, is the process by where norms established, help towards the interest of the social group/network (Coleman, 1988). However, in social structures where there is low negative external effect and higher positive ones, these norms do not exist (Coleman, 1988). The current study focuses on the first two forms of social capital, obligations and expectations and information channels.

**Methodology**

This two-year study focuses on fifty-three Black male engineering students at a minority serving institution in the United States of America. The paper focuses on the preliminary findings gathered during year one of the study.

The fifty-three Black male student participants represented various engineering majors in the engineering college. All six engineering majors were represented with the largest percentage (59.2%) of students coming from mechanical engineering and electrical engineering. The remaining 40.8% of the participants were enrolled in computer engineering, chemical engineering, computer science and civil engineering. The study participants were predominately US born Black males (72%) with a small sample of international Black male students (28%). While efforts were made to make these populations representative of the population within the engineering college, student participation was limited for the international group. Grade point average for each term was self reported for preliminary analyses. Final grades were unavailable from the university’s registrar office to measure academic achievement.

Quantitative and qualitative data were gathered from surveys, structured interviews, and focus groups during the second semester of the participant’s first year. The student survey instrument used to collect quantitative data was a modified version of the Persistence Survey (Eris et al., 2005). This instrument, probed the extent of participants’ social and academic integration in their engineering programs. Based on the Social Capital Theory, items measured students’ perceptions of obligations, expectations and information channels among peers and between faculty members and students. These questions included but were not limited to academic advising and faculty mentorship. Surveys were administered to all student study participants. Descriptive statistics were computed on survey data.

Thirty-five of the fifty-three participants were selected to participate in semi-structure interviews. The semi-structured interviews provided the collection of more detailed information related to the use of social capital in the engineering major and its impact on persistence, and its relationship to the instructional and social culture of the university. In addition, select students were asked to participate in homogeneous focus groups that were based upon nationality and school classification. Focus group questions were...
generated from topics needing further exploration that may not have been adequately addressed in the survey or semi-structured interview.

**Major Findings**

Descriptive statistics were used to analyze survey questions to examine if academic achievement was in fact related to the social capital areas of academic advising and other engineering experiences. The results are described below.

To understand how social capital impacts academic achievement in engineering, we examined faculty involvement, the relationship of grade point average to satisfaction with academic advising, summer research experiences and the influence of engineering experiences (coursework, internships, research) on doubt and decisions to continue in the major. When student participants were asked if a faculty member encouraged them to pursue engineering, only twelve percent (12%) of students indicated that faculty members played a part in their decision. While many students were not encouraged to become engineers by faculty, students with higher reported grade point averages did indicate satisfaction with academic advisement from faculty members.

As shown in Table 1, over eighty percent (80%) of student respondents with an “A” average indicated satisfaction with the quality of academic advising, by not only faculty, but also their teaching assistants in engineering courses. However, the percentage of satisfaction shows a decreasing trend among student respondents with B averages and below (Table 1). Students with C and D averages report no satisfaction with regard to the quality of academic advising they have received during the academic year.

<table>
<thead>
<tr>
<th>Engineering Grade Point Average</th>
<th>Percent Satisfied with Quality of Faculty Advising</th>
<th>Percent satisfied with Quality of Teaching Assistant Advising</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>77.5</td>
<td>83.5</td>
</tr>
<tr>
<td>B</td>
<td>59.7</td>
<td>37.0</td>
</tr>
<tr>
<td>C</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>D</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Students were also asked about their involvement in engineering activities during the summer. These activities included coursework, internships, and research. An average of eighteen percent (18%) of the respondents indicated that they had participated in events relating to engineering coursework, internships, or research during the summer. Of the students partaking in summer engineering activities, sixty seven percent (67%) reported that these activities advanced their interest in pursuing an engineering degree.

In a closer examination of engineering experiences, research opportunities were further clarified. In this vein, students were asked if they had participated in a research experience since coming to college. Thirty five percent (35%) of student respondents had a research experience in the engineering field since coming to college. Moreover, nearly all of the students involved in research reported a B or better grade point average.
Not only were students asked about their initial interest in pursuing engineering, and participation in engineering activities, but students were also asked to indicate influences on their decisions to continue in engineering, as well as, the causes for any doubts relating to their decisions to matriculate. As can be seen in Table 2, experiences in engineering (rigorous coursework, internships/research/and interactions with faculty) were an indicator of engineering continuation for over fifty percent (50%) of ‘A’ students. Students with ‘C’ and ‘D’ averages indicated that their primary reasons for continuing in the engineering field were their experiences from pre-engineering programming or activities from other disciplines. The table also shows that engineering experiences for some students, regardless of academic achievement level, creates doubt in students regarding their continuation. This indicates that while students find that their experiences within the rigors of the engineering course work, research, and internships aid in their desire to continue in engineering; these very same experiences discourage students to continue in the field.

<table>
<thead>
<tr>
<th>Engineering Grade Point Average</th>
<th>Decision to CONTINUE come from:</th>
<th>My DOUBTS about continuing came from:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Engineering Experiences Percent</td>
<td>Other (non engineering) Experiences Percent</td>
</tr>
<tr>
<td>A</td>
<td>51.2</td>
<td>22.5</td>
</tr>
<tr>
<td>B</td>
<td>40.6</td>
<td>30.9</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

It must be noted, that fifty-eight percent (58%) of ‘A’ students never doubted pursuing an engineering major. This lack of doubt holds true for twenty five percent (25%) of ‘B’ students and one hundred percent (100%) of ‘C’ students.

**Conclusion**

In this paper we discuss the preliminary findings regarding social capital and Black male engineering students at a minority serving institution. The data suggest that while there is a great deal of research relating to the use of social capital in general, there is much to understand about how black male engineering students utilize the social capital available to increase their academic achievement in engineering. Based upon the quantitative data presented, many of the social capital available are under utilized by black male students. More importantly, the very students in need of support (B and below) are the very students reporting dissatisfaction, and lack of research and internship experiences in engineering. As Coleman (1988) asserts, this could be due to exclusivity when sharing information across individuals. Social norms in higher education tend to provide extra opportunities to the excellent students. This however, may undermine the achievement of students that need to be drawn into their major for graduation and career success.
While social capital has proven itself to be vital to for academic success (Palmer and Gasman, 2008), the issue that arises is access versus utilization. We must better understand what is being provided and to whom these services are accessible. Further, it paramount to understand the reasons students are participating to discern social capital’s impact on academic achievement for black male engineering students. Contributions of future work include an in depth understanding of the importance of social capital for black male students at a minority serving institution. To further elucidate our findings, our next steps will consist of triangulating qualitatively coded student and faculty interviews with survey data and student focus groups. Upon final analysis, the present investigation will not only provide insight into students’ perspectives and the reasons they have or have not taken advantage of these capital, but also faculty perspectives on the social capital required for completion in the engineering major and why these capital are not utilized.

References


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Understanding engineering self-efficacy of students involved with a professional minority engineering society

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Abstract: To measure the engineering self-efficacy of student members of the National Society of Black Engineers (NSBE) the authors administered the LAESE (Longitudinal Assessment of Engineering Self-efficacy) instrument to 63 undergraduate members (37 males, 26 females) during a regional conference and general body meetings. LAESE measures engineering self-efficacy, coping efficacy, feeling of inclusion, and outcome expectations. The authors posited that members of NSBE have high engineering self-efficacy because of the resources and programs NSBE offers. Results showed no significant difference in coping self-efficacy, math outcome expectations, engineering self-efficacy, and engineering career success expectations for men compared with women in NSBE. Men in NSBE were also found to have a higher feeling of inclusion than women.

Background

With the United States ranking in the mid-teens in science and math, the inability to compete in the areas of Science, Technology, Engineering and Mathematics (STEM) has the potential to be a growing problem, especially for underrepresented students (i.e., all women and racially ethnic men) (National Science Foundation [NSF], 1996). Gaps in race/ethnicity at entry and in completion of STEM programs indicate the United States’ struggle to develop a diverse workforce (National Research Council [NRC], 1999, 2003). As indicated by our past two Presidents, there has been an increased discussion on the national and state level regarding the number of students entering STEM disciplines in general and underrepresented minority students in particular. The percent bachelor's degrees in engineering awarded to women and underrepresented minorities has been steadily declining over the past decade. While three key underrepresented minority (URM) groups, African Blacks, Latinos, and Native Americans constitute some 30 percent of the overall undergraduate student population in the United States, the share of engineering degrees earned by members of these groups declines as degree level increases. Underrepresented minorities accounted for about 12% of engineering bachelor’s degrees award in 2009, 7% master’s degrees and 3% of doctorates (National Action Council for Minorities in Engineering [NACME],2009). The percent in engineering has been steadily decreasing, while overall participation in higher education among these groups has increased considerably. Some researchers attribute the high dropout rate of women and underrepresented students in STEM programs to low engineering self-efficacy.
To combat low engineering self-efficacy students join professional societies such as the National Society of Black Engineers (NSBE).

The National Society of Black Engineers (NSBE) is an organization whose mission is “to increase the number of culturally responsible Black engineers who excel academically, succeed professionally and positively impact the community.” The philanthropic organization was founded in 1975 by six Black students, coined the “Chicago six” at Purdue University. These men set out to start an organization dedicated to the recruitment and retention of Black students in engineering. Over the years NSBE has evolved and grown into a global organization with nearly 30,000 members. In 1988, NSBE expanded and incorporated NSBE Jr. chapters to help increase the number of Black students exposed to math and science in hopes that one day they will see engineering as a future field of study. Thereafter the Pre-College Initiative (PCI) program was launched to help NSBE build its pipeline by including students in grades 6 through 12. Today NSBE is one of the largest student run organizations in the United States with over 2,000 elected leadership positions, 12 regional conferences and an annual convention. The society offers academic excellence programs, scholarships, leadership training, and professional development. The opportunities NSBE provides are unparalleled to any other student organization running today (National Society of Black Engineers [NSBE], 2011). The leadership development, academic programming, mentoring, and networking available to NSBE members has the potential to help increase their engineering self-efficacy.

The following theoretical framework provides a basis for helping understand self-efficacy as it relates to Black students in engineering.

Theoretical Framework

Social Cognitive Career Theory

Lent et al. (2003) developed the Social Cognitive Career Theory (SCCT) by expanding Bandura’s (1991) Social Cognitive Theory (SCT). SCCT includes environmental, behavioral, and other variables that develop a person’s academic interest. This theory has been widely accepted in engineering education research and has been used as a way to help predict students’ academic interests and goals in engineering (e.g. Lent et al. 2005). SCCT is used to understand how people develop academic and career interests, make and revise their educational/vocational plans, and achieve quality performance in their chosen academic and career quest.

SCCT identifies self-efficacy, outcome expectations, goals, and other factors that help shape a students’ career path. Understanding this theory provides a foundation to comprehend self-efficacy.

Self-Efficacy

According to Bandura (1991), self-efficacy is a person’s belief about their capability to exercise control over events that affect their lives, such as completion of a college degree.
Bandura (1986) argues that self-efficacious perceptions are developed by a person's vicarious experiences (seeing someone else complete a task and believing you can do the same), mastery experiences (previous success leads a person to believe he/she is capable of completing a similar task), physiological state, and social persuasions (supportive people in a person’s life such as a teacher or mentor). A person's belief about their efficacy potentially influences their goals, behavior, and how they persist in the face of obstacles.

Engineering self-efficacy is a person’s belief that he/she can successfully navigate the engineering curriculum and eventually become a practicing engineer. Strategies for increasing engineering self-efficacy in Black students have the ability to improve their retention in engineering.

**Relevant Research**

Ohland (2002) found that students from Florida A&M University (FAMU) who participate in the minority engineering programs are 25% more likely to graduate than students who do not participate. Their minority engineering program consists of the Engineering Concepts Institute (ECI), where students come for a six week program over the summer to learn engineering fundamentals, the cooperative academic resources for excellence (CARE) program, designed to increase a students’ engineering awareness, and the Department Learning Center (DLC) program, facilitated in the freshman and sophomore years instructing students on skill and processes. The programming offered at FAMU is similar to that offered through NSBE. The effect of these programs is directly correlated with retention and graduation rates.

To address the decline of minority students in engineering degrees, the study conducted by Reichert (1997) worked to recommend minimum improvements Universities could implement to help retention and graduation of Black students in Engineering. In the study 13 institutions were identified as meeting or exceeding the target minority retention ratio set by NACME in 1991. The best practices amongst these Universities were analyzed and out of the 13 institutions, 12 of them had active NSBE chapters.

At Purdue University, Hutchison (2006) studied factors influencing the self-efficacy beliefs of first-year engineering students. After administering the engineering efficacy survey, they found nine influential factors; Understanding/Learning, Drive and Motivation, Teaming, Computing Abilities, Help, Working Assignments, Problem-Solving Abilities, and Enjoyment/Interest/Satisfaction. This study helps support Bandura’s framework for self-efficacy belief.

**Research Questions**

The authors wish to understand engineering self-efficacy of students involved with professional minority engineering societies, specifically, the National Society of Black Engineers. Particularly:

1. What factors are significant to NSBE members’ engineering self-efficacy?
2. Does involvement in NSBE constitute high self-efficacy?
3. Are there differences in engineering self-efficacy of women vs. men in NSBE?
Gaining an initial understanding of these questions will provide the authors with a basis to develop strategies for recruitment and retention of Black engineering students to NSBE, and ultimately improve retention for Blacks in engineering, bridging the engineering diversity gap in the United States.

**Methodology**

**Subjects**

Subjects were 63 undergraduate engineering students who consented to participate. Each student is a member of the National Society of Black Engineers (NSBE). The distribution of the sample by class (Table 1), and gender (Table 2) is provided below. There were 15 freshmen in the sample, 17 sophomores, 16 juniors and 15 seniors. The sample included 37 males and 26 females.

<table>
<thead>
<tr>
<th>Class</th>
<th># Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshman</td>
<td>15</td>
</tr>
<tr>
<td>Sophomore</td>
<td>17</td>
</tr>
<tr>
<td>Junior</td>
<td>16</td>
</tr>
<tr>
<td>Senior</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>63</strong></td>
</tr>
</tbody>
</table>

Table 1: Distribution of sample size by class

<table>
<thead>
<tr>
<th>Class</th>
<th># Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>37</td>
</tr>
<tr>
<td>Female</td>
<td>26</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>63</strong></td>
</tr>
</tbody>
</table>

Table 2: Distribution of sample size by gender

**Instrument**

The LAESE (Longitudinal Assessment of Engineering Self-efficacy) instrument was created, tested, and validated to measure self-efficacy, inclusion, and outcome expectations by Marra and Bogue (2006). The subscales measured by the LAESE instrument are as follows:
1. Engineering career success expectations
2. Engineering self-efficacy
3. Feeling of inclusion
4. Coping self-efficacy
5. Math outcome expectations

Questions related to each subscale were designed to identify supports students have and barriers they face while pursuing an engineering degree, which ultimately determines their engineering self-efficacy. When analyzing the data you would expect to see an increase in subscale averages as a student progresses through his/her academic tenure, indicating their engineering self-efficacy, feeling of inclusion, etc., increases as they progress through their major.

**Administration**

During the fall 2010 semester several avenues were taken to gather a pool of students to sample. The survey was administered to NSBE members during two general body meetings at a medium institution in the Midwest of the United States and a large institution on the east coast of the United States. Surveys were also administered during a workshop at the National Society of Black Engineers Region II Fall Conference. The number of students surveyed by major is shown in Table 3. There was nearly an even distribution of student members who participated in the study majoring in Biomedical, Chemical, Civil, Computer, Electrical, Materials, and Mechanical Engineering. Students were given time to read the consent form and were made aware that their participation was voluntary. It was impossible to survey 100% of NSBE’s membership, but the sample collected suits the needs of this analysis.

![Table 3: Distribution of sample size by major](image-url)

<table>
<thead>
<tr>
<th>Major</th>
<th># Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomedical</td>
<td>8</td>
</tr>
<tr>
<td>Chemical</td>
<td>9</td>
</tr>
<tr>
<td>Civil</td>
<td>9</td>
</tr>
<tr>
<td>Computer</td>
<td>7</td>
</tr>
<tr>
<td>Electrical</td>
<td>9</td>
</tr>
<tr>
<td>Materials</td>
<td>8</td>
</tr>
<tr>
<td>Mechanical</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>63</strong></td>
</tr>
</tbody>
</table>
Results

The data collected was examined to answer the following questions:

1. What factors are significant to NSBE members’ engineering self-efficacy?
2. Does involvement in NSBE constitute high self-efficacy?
3. Are there differences in engineering self-efficacy of women vs. men in NSBE?

Table 4 provides the subscale means by gender for the sample under consideration. The questions in the survey instrument use a 7 point scale (1 - Strongly Disagree, 7 - Strongly Agree). Students were tasked to indicate the level to which they agree with statements in the survey (i.e. Strongly Disagree, Disagree, Slightly Disagree, Disagree nor Agree, Slightly Agree, Agree, Strongly Agree). For example, there were three questions included in the math outcome expectations subscale:

1. Doing well at math will enhance my career/job opportunities
2. Doing well at math will increase my sense of self worth
3. Taking math courses will help me to keep my career options open

Taking a look at the mean scores in Table 4 the authors do not see major difference in coping self-efficacy, math outcome expectations, engineering self-efficacy, and engineering career success expectations for men vs. women. Men in NSBE had higher mean values for feeling of inclusion than did women in NSBE.

<table>
<thead>
<tr>
<th>LAESE Subscales</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coping Self-Efficacy</td>
<td>5.57</td>
<td>5.60</td>
</tr>
<tr>
<td>Math Outcome Expectations</td>
<td>5.42</td>
<td>5.40</td>
</tr>
<tr>
<td>Feeling of Inclusion</td>
<td>4.88</td>
<td>4.26</td>
</tr>
<tr>
<td>Engineering Self-Efficacy</td>
<td>5.53</td>
<td>5.64</td>
</tr>
<tr>
<td>Engineering Career Success Expectations</td>
<td>5.70</td>
<td>5.68</td>
</tr>
</tbody>
</table>

Table 4: Comparison of subscale means by gender

The subscale means for the entire sample are provided in Table 5. Again, the data shows that NSBE members in this sample have a low feeling of inclusion in engineering, which is surprising considering the large network of Black engineers they belong to.

<table>
<thead>
<tr>
<th>LAESE SUBSCALES</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coping Self-Efficacy</td>
<td>5.59</td>
</tr>
<tr>
<td>Math Outcome Expectations</td>
<td>5.41</td>
</tr>
<tr>
<td>Feeling of Inclusion</td>
<td>4.57</td>
</tr>
<tr>
<td>Engineering Self-Efficacy</td>
<td>5.59</td>
</tr>
<tr>
<td>Engineering Career Success Expectations</td>
<td>5.69</td>
</tr>
</tbody>
</table>

Table 5: Comparison of subscale means by gender
Discussion

The authors’ conjecture that members of NSBE have high engineering self-efficacy was found to be conflicting. Subscale questions were on a 7 point scale, and none of the subscale means reached above a 6. The sample also has a relatively low feeling of inclusion. The highest subscale mean was for that of engineering career success expectations. This is no surprise as one of the primary reasons students join NSBE is because of the career fairs and other employment opportunities and resources the organization offers.

Taking a look at the questions under each subscale and comparing them with the highest subscale averages, the authors speculate that factors significant in determining NSBE members’ engineering self-efficacy are being able to adjust to new campus environments, having a lot in common with students in their classes, and relating to the people in their extra-curricular activities. As NSBE is a large network of Black engineers, being able to relate to people in your major who “look like you” definitely increases a NSBE members’ feeling of inclusion and engineering self-efficacy.

Future Research

What about Black students who are not involved with NSBE? Does their engineering self-efficacy differ from that of NSBE members? Future research will address this question.

References


Acknowledgement

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Defining Diversity: Impacts on Students' Engineering Identity

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Abstract: Evolving out of the United States' civil rights movement of the 1960s and 1970s, diversity became the buzz word for racial and gender integration. After years of educational and professional diversity initiatives, today's American students have redefined diversity into a term that is starkly different from eras before. This paper details findings from a 4-year longitudinal, mixed-method study of 63 engineering undergraduates from four distinct universities. Related questions focused on race and gender revealed impacts on students' engineering identity and academic experiences. By reviewing data from students' sophomore and junior years, we further explore how students' views on diversity and identity change over time. Emergent themes suggest that students' perceptions of race and gender contribute to the formation of their engineering identity.

Background

Developing research on the current state of diversity in engineering indicate that engineering is among other STEM (Science, Technology, Engineering, and Mathematics) industries that continue to face unique challenges to meet diversity needs (Chubin, May & Babco, 2005). Researchers continue to explore the possible reasons that underlie the unusually high dropout rate in engineering education, particularly among women and minorities. This research has unveiled consistent trends that indicate women and minorities who begin their undergraduate careers in engineering not only experience higher rates of attrition but are also more likely than their white male counterparts to change majors and graduate with degrees in other fields (French, Immekis, Oakes, Williams, 2005). Engineering education's high women and minority attrition rates continue to puzzle researchers despite the fact that other STEM fields persist to retain and recruit more of these students with similar retention and recruitment endeavors (Nolen, 2003).
The disparities in engineering education among women and minorities become evident when one reviews the current science and engineering baccalaureate representation. According to data from the National Science Foundation, in 2008, women earned more than half of the degrees awarded in psychology (77.1%), physical sciences (41.2%), and social sciences (53.5%), and almost half (43.9%) in mathematics. However, women received only 18.5% of bachelor's degrees awarded in engineering, 17.7% in computer sciences, and 43% in physical sciences (NSF, 2011). Although the salary potential is increased for graduates who choose a degree in engineering over other fields, low matriculation in engineering studies persist despite the monetary advantages (NSF, 2011).

This paper aims to explore the findings from the Academic Pathways Study (APS) that highlighted students' views on diversity as described during their sophomore and junior year of undergraduate study. The focus of this paper is to offer some insight into how engineering students define diversity over time and what ways, if any, diversity plays a part in their engineering identity. While the APS student sample is not meant to generalize other engineering students' experiences, the study does, however, contain descriptive personal accounts of engineering students from across a broad demographic of the U.S.

As a social construct, diversity evolved as a method to increase social welfare and promote a more integrated community. It reigns as one of the most important issues in academia and the corporate arena because of its critical social implications. Diversity helps ensure that educational and professional opportunities are dispersed among a variety of social groups, who in turn, increase the institution's and industry's ability to incorporate new ideas and service a variety of populations. Although not yet realized, steady growth in engineering diversity is a main goal of several federally-funded programs, administration initiatives, and the engineering industry in general (i.e. NSF, National Science Board, White House Initiative on STEM Fields). Unfortunately, previous literature describing the perceptions of engineering students regarding diversity is nearly non-existent. Due to the sensitive nature of diversity issues, past investigations seeking to illicit personal views on diversity may have had special challenges. As such, researchers realize that investigating concepts of diversity have natural limitations. Respondents' comfort level and their ability to personally operationalize diversity are primary issues in this type of investigation.

**Research Questions**

This paper explores the following four research questions which were examined longitudinally:

1. How do students' perceptions of gender affect their views on becoming an engineer? How does it develop and change over time?
2. How do students' perceptions of race affect their views on becoming an engineer? How does it develop and change over time?
3. How does students' definition of diversity or change over time?

**Theoretical Framework**

The theoretical framework discussed in this study seeks to provide the reader with an understanding of the learning theories that underlie issues in diversity such as
perceptions of gender and race, and occupational (engineering) identity formation. Essentially, this framework is used to support the argument that students’ perceptions of experiences relating to gender and race may affect their views on becoming an engineer. The Phenomenological Variant of Ecological Systems Theory (PVEST) (Spencer, Dupree, Hartmann, 1997) combines Bronfenbrenner’s ecological systems theory with other self-organization perspectives. PVEST encapsulates the preeminent theme in human development that acknowledges the complex interaction of various domains of human functioning. Using the classroom as a context in which identity is formed, Spencer et al. (1997), discusses the relationship between healthy identity formation, a major crossroad in human development, as a predictor of positive identity development. Spencer defines identity as a —psychological element that...maintains an individual's sense of self and others' through development changes...identity processes become defined specifically by how individuals make meaning of their own experiences and the contexts they encounter at multiple levels‖ (Spencer, et.al, 1997, p. 818). Within the ecological setting, student’s identification with academic achievement and high status occupations (such as an engineer) is mediated through self-appraisal and feedback. PVEST asserts that the perception of experiences in different cultural contexts influences how students perceive themselves. For example, a young Asian American student may take advantage of the perception that he or she is perceived as a —model minority‖ by the larger society. He or she may choose to excel academically to meet the expectations of teachers, peers, and family members. Conversely, many other minority students (i.e., students of African American, Hispanic & Latino, and Native American heritage) may not benefit from such societal perceptions of academic excellence and therefore may feel incapable of battling the existing low performance stereotypes integrated within their cultural self-perception.

Methodology

Four distinct American universities participated in the data collection during the 2003-2007 academic years. In order to provide anonymity to each participating university, a pseudonym is used: 1) Engineering Public Institution (EPI), a public mid-western university specializing in teaching engineering and technology; 2) Historical Private University (HPU), a private Historically Black University in the Mid-Atlantic region; 3) Metro Public University (MPU), a large public university in the Northwest U.S.; and 4) Pacific Private University (PPU) a medium-sized private university on the West Coast.

This paper focuses on the data collected from 63 individual structured interviews with engineering students administered at all four institutions. Although the larger study employed multiple instruments, this paper solely focuses on a sub-study of student responses to the structured interviews that were collected during the sophomore year and again in their junior year. Although 105 students were surveyed, only 63 of these students completed an interview during both their sophomore and junior years. Both sophomore and junior year findings were analyzed using quantitative and qualitative methods. Structured responses were analyzed using NVivo 9 qualitative software where responses were coded. Gender and racial themes and patterns quickly emerged.
Among other questions, students were prompted with the following questions during their sophomore and junior year interviews:

1. What does diversity mean to you?
2. To what extent do you consider your school to be diverse?
3. Does your gender affect your view of becoming an engineer? If yes, how?
4. Does your racial identity affect your views of becoming an engineer? If yes, how?

**Major Findings/Conclusion**

**Defining Diversity**

Responses reveal that students define diversity in many different ways although they discussed the more familiar terms associated with diversity; however, some students discussed less widely used references. In general, students defined diversity as having a representation of people with varying personal attributes. Common references emerged in diversity such as gender, race, culture, and ideology. Less common definitions of diversity emerged from student responses which included well-roundedness, acceptance and tolerance, diversity of academic majors, and socio-economic status. Sophomore year data revealed that students were challenged at varied levels to define diversity. For example, some students found it very difficult to articulate what diversity meant to them. Brandon from HPU said, ―Diversity? ... a mix. ..different kinds of people. ... flavors...‖. Other students had little difficulty defining diversity. For example, John from HPU stated, ―I believe that diversity is an opportunity for people [of] different minds and different backgrounds to come together and bring about... I mean, put their ideas together to make something that is good for everyone‖.

Longitudinal analysis of the data from both the sophomore and junior years revealed that student’s definition of diversity did not significantly change. An interesting theme, however slight, emerged from the data when evaluating how young men and women conceptualized diversity. Of the wide range of divergent views on diversity, men defined diversity as having different ideas and thoughts more often than female respondents who were asked the same questions. Likewise, women defined diversity as difference in culture more often than male respondents who were asked the same question. This glimpse into gender differences in the construct of diversity shows that establishing diversity within an institution or industry may have different meanings depending on one’s gender.

**Gender Roles and Engineering Identity**

Data from both the sophomore and junior years consistently revealed that males and females have differing views on the extent that their gender affects their view of becoming an engineer. Independent samples T-test of the sophomore year data displayed the gap between female and male students’ perceptions about gender and becoming an engineer \(t=2.25, p=.026\). Having a lack of role models was significantly associated with being female \(t=2.369, p=.020\). There were no other significant relationships found. In their sophomore year, almost two thirds (63%) of all students said that their gender did not affect their views of becoming an engineer.
The longitudinal analysis of sophomore and junior year data show that only 9.5% of students changed their response to whether gender affects their view on becoming an engineer. Four out of the six students who changed their response are male students who discuss how the engineering career aligns with their perception of the male role identity. For example, Josh from PPU said —...If we’re talking about traditional, stereotypical gender roles in America, I guess, you know, maybe I decided to become an engineer instead of a teacher because—you know, guys are supposed to become engineers or businessmen or something like that.|| Also, Mary from MPU discussed her reasons for the change, —Because I know how few women there are in engineering... It won’t stop me but sometimes I do think about it well like what is it going to be when ... I get a job?||

An interesting theme emerged from the data that indicated that 25% of the males who responded in both sophomore and junior year interview agreed that gender had affected their views on becoming an engineer. One hundred percent of these responses indicated that their perceptions of the male gender role aligned with their self-identity as an engineer. For example, Shane of HPU said, —...Where I grew up... engineer[ing], is a male field; it’s one of those strong male fields that goes with law and medicine,...it slightly affected my decision, _cause as a man if you're,[on] top, those are the top fields that you're trying to get into as a man]. Also, Bradley from MPU stated —Uh yea I think ... there is definitely a stereotype that males are in engineering]]. Monty from EPU shares; —Um, I don't know... I mean ... there tend[s] to be more males than females... in most engineering professions and I guess I am aware of that and ...I see it in most of my classes that there is a lot more guys than girls in classes but ... it’s something ... which... changes about how I feel about things]]. Among these male respondents who confided that their gender affected their views on becoming an engineer, they also discussed an understanding and internalization of common male identity stereotypes and expectations.

Of the female respondents that were interviewed in both their sophomore and junior years, 52% indicated that gender was a factor in becoming an engineer. Women who expressed that gender affect their views on becoming an engineer also discussed the perception of gender roles and engineering identity. Joyce from MPU said, —Yes. Partially because of the stereotype that females are not good in math and science. It's never been a big stepping stone for me to get over that but ...I can see it there's not a lot of females in engineering...]]. Many of these female students express understanding of the dominant stereotypes but also indicate how overcoming stereotypes motivates them to excel academically. Karen from EPI also added —Yes, I think it does, knowing that females are such a low percentage of um, engineers, it encourages me to be one of those people to get the word out to have more females um, in the field of engineering]]. Mabel from IEP also added, —I mean, that does help change our perspective on being an engineer, _cause I'm female, because I'm a minority and I'm not used to being like that because I'm a white middle class individual, but ah, I dunno, ... it's hard to become an engineer, it's real intimidating to be... working for... predominantly all males, but at the same time, it's kind of a challenge to me, I can do this, I can pioneer this and be a female engineer, be just as good as a male engineer]].
Race and Engineering Identity

Students were surveyed to share their thoughts on how they perceived their race affected their views of becoming an engineer. During the initial interview during the sophomore year 81% replied that race had no impact on their views of becoming an engineer. However, the longitudinal data analysis over the course of the sophomore and junior years revealed that nearly 13% of students who participated in both years of the study changed their opinion on how their race affected their views on becoming an engineer. In fact, all students who changed their opinion to this specific question agreed that their racial identity, indeed, had an impact on their engineering aspirations. An interesting theme also emerged from this prompt that suggests that many students are aware of the racial stereotypes and expectations surrounding the engineering industry. Nearly 15% of students who participated in both years expressed an understanding of the link between race, stereotypes, and aspirations to become an engineer. For example, Michael an Asian American student from MPU stated, —Well I guess maybe cause I think a lot of Americans perceive Asian people are into Math and that’s why my dad was always telling me that math and science were fields I should concentrate on‖. Mark, an Asian American student from EPU also articulated that being Asian did not negatively affect his views; he shared, —Not so much, like, I’m Asian, plenty of other engineers that are Asian, I don’t really think it affects anything about our engineering future‖. Eddie, a sophomore from EPU, shared: —... I don’t see...my race being a huge... factor in being an engineer, but...I think that at times since I’m Asian, that I fall into the stereotype of being a smart Asian sometimes, so I think, in that aspect it kind of ... influences, but it doesn’t mean that that’s all that defines why I’m planning to study engineering‖. Carlos, a Hispanic exclaimed —...No, maybe if I was like another race...people still tell me I look white...my being Spanish has in ...no way shape or form [affected] anything...so I don’t celebrate Cinco de Mayo or anything....‖ Finally, Abe, a Caucasian student from MPU expressed his thoughts on stereotypes and expectations. —If I was African American or if I was Mexican or a non-Asian person or a non-white since there aren’t very many Asians or since there aren’t very many people with similar racial backgrounds it might have an effect because you know you can’t... It doesn’t [have an effect] because I’m lucky to be born white...‖

One hundred percent of the students who offered commentary about their racial identity and stereotypes or expectations to become an engineer were Asian American or Caucasian. Asian American students comprised almost the entire student group who discussed their familial expectations to become successful and/or the dominate stereotypes of Asian intellectual superiority. These expressions offer researchers a glimpse into the processes of engineering identity formation. Although these students were not asked directly about racial stereotypes or expectations, these students seem to easily grasp the link between cultural experiences and emergent identities.

Implications/Recommendations

Several themes emerged from the data that suggest that continued effort is needed to recruit women and minorities in engineering education. Utilizing PVEST as a framework to understand how students identify with and relate to a career in engineering, this study has...
added to the body of knowledge that suggests that existing stereotypes are hugely credible in the growth of students’ engineering identity as well as offering hurdles in the identity formation process of underrepresented students. Data from both years consistently uncovered students’ views that perpetuated widely held stereotypes and beliefs. Asian American students were far more likely to discuss their perceptions of race that was closely aligned with their engineering careers aspirations. Conversely, women and African American students were far more likely to discuss the gender and racial stereotypical challenges. Men in general were more likely to discuss the close match between their gender identities and plans to become an engineer. Finally, many students discussed their perceptions of the under-performance of or discrimination against other students who were women or minorities. Interestingly, despite the somewhat clear understanding of unfair but widely held gender and racial stereotypes, many students still seem to perpetuate the beliefs that serve as a foundation to discriminatory practices.

Junior year data showed that marginal views had changed during the course of the year; however, the students whose views had changed overwhelmingly agreed that their gender and/or race had impacted their decision to pursue engineering as a career. These results suggest that increased presence of underrepresented women and minorities can challenge existing stereotypes surrounding engineering to produce a more diverse industry. Insights also combat current beliefs that racial and gender stereotypes are reminiscent of a distant past; although less common, past stereotypes continue to burden potential engineering professionals.

Finally, when studying issues with such paucity as diversity, researchers must consider employing both qualitative and quantitative methods. For quantitative researchers, it may seem uncomfortable to focus attention on the outliers that emerge from the findings, rather than focusing on the majority. However it is the voices of such outliers that normally are lost in aggregated statistical analyses and remain unheard. These voices are significant enough to begin to produce monumental change that can affect all, the majority and minority.

Acknowledgements

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References


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Session 7: Friday morning

Topic: Educational Research – Chair: Maizam Alias

The bigger picture - capturing value creation for an engineering school as it initiates engineering education research

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Abstract: To help those introducing engineering education research in contexts where there is no existing tradition for this kind of research, this paper looks at an approach to value capture based on a learning community cultivation model developed by Etienne Wenger which uses a five cycle assessment framework. The framework captures the value of this type of research more comprehensively than more traditional indicators like research output and can be useful both for preparing return on investment reports for administrators and for planning new research projects. Here we exemplify its application for a 3-year nationally funded project and compare this approach with an alternative one.

Introduction

When attempting to introduce engineering education research (EER) in an engineering school the challenges include a lack of legitimacy in relation to mainstream engineering research and the fact that there may be no tradition and little institutional support for such investigation. In addition it may be difficult to demonstrate clear gains in the early years so to justify the time and opportunity cost involved for faculty or institution. This may be mitigated in part by recognition gained through successful application for external research funding but even then it may not be easy to demonstrate the value of the introduced changes within the timeframe and often narrow framing of goals and milestones (journal articles, conference papers, patents or PhDs awarded) associated with such funding. For this reason, we have explored the potential of various approaches for measuring change (Kantor & Lehr, 1975, Ancona, Bresman, & Kaeufer, 2002) and for capturing value (Wenger et al, 2011) as a result of EER interventions in an institution.

This paper focuses on an approach to value capture based on a learning community cultivation model developed by Etienne Wenger which uses a five cycle assessment
framework. It ascribes five stages or cycles of value in the evolution of a learning community and we believe they are relevant to the evolution of EER interventions. Wenger and his co-authors propose a progression through the following learning cycles of value creation:

1. Immediate value: activities and interactions
2. Potential value: knowledge capital
3. Applied value: changes in practice
4. Realized value: performance improvement
5. Reframing value: redefining success

Background

In the work described here, we apply the framework to a recently completed three year nationally-funded research project which set out to use a community of practice approach to introducing active and cooperative learning techniques in lecture classes through the design of a learner activity monitoring instrument.

Methodology

We believe this is first time this particular framework has been applied as a lens in the field of EER and as this essentially exploratory research a qualitative methodology has been adopted.

Research question

Can this framework be recommended as an instrument to capture the value of an EER project?

Procedure

The information presented is based on data gathered from interviews with the engineering lecturers who formed part of the core group of the Active Learning research project and validated by inviting the respondents to comment on the transcriptions of their interviews at the end of the three-year period. This data is supplemented with other narrative and institutional data gathered during the time the project was underway.

The structure of the paper follows that proposed by Wenger et al for the five cycle assessment framework in that we exemplify each the cycles in the context of one of the schools participating in the project mentioned above.

Cycle 1 Immediate value: activities and interactions

The most basic cycle of value creation considers networking and community activities and interactions in and of themselves.

In this case, activities of the core community included:
3 or 4 of meetings the core group per semester. Once the overall goals and tasks had been defined, these meeting were mainly design-focused to improve the LAMM and observation procedures; observation of lessons of members of the group by group members (peer observation);
observation of lessons of members of the group by student grant holder;
recording lessons of members of the group using video camera;
participation in 13 international conferences – (involving 8 group members);
13 peer-reviewed conference papers, 3 other conference papers (5 group members);
3 poster presentations (5 group members);
holding monthly active learning seminars for other engineering faculty members in 2009 and 2010.

Cycle 2 Potential value: knowledge capital

Not all the value produced by a community or a network is immediately realized. Activities and interactions can produce "knowledge capital" whose value lies in its potential to be realized later. Aside from its role in community cultivation, the concept of knowledge capital within higher education institutions has been the object of increasing interest on the part of economics researchers in recent years as R&D allied to the cultivation of positive network externalities and knowledge spillover are believed to contribute to increasing entrepreneurship and subsequent national growth in the long term (Acs et al 2009, Baptista et al 2011, Romer 1990).

Although the work described here was originally seen as focused on improving teaching and learning in the classroom, it did also lead to ancillary research and collaboration with innovative engineering companies as will be described below.

The framework we are employing has five sub categories for the knowledge capital cycle which will now be outlined in relation to the case under study:

Personal assets (human capital)

This can take the form of a useful skill, a key piece of information, or a new perspective and included the following:

- Running pedagogy sessions for peers not involved with the project. This peer sharing process involved participation from all the 7 core members and additionally 3 other colleagues who became involved as the project progressed;
- Experience speaking to peers (in Portuguese) about a new area of competence;
- Experience speaking in public (in English) about a new area of competence;
- One external graduate student and two undergraduate students of the school received grants to participate in the research – the latter not being common practice in Portugal;
- New classroom teaching techniques;
- Relating to students in the classroom in new ways;
- Experience in observing and being observed in a systematic way in the classroom;
- Experience in design-based research;
• Using the LAMM tool;
• Using videoconference and web 2.0 tools;
• Using Skype for audio conference.

**Relationships and connections (social capital)**

When one considers knowledge as a collective good distributed across a community or network, then social relations and connections are a form of knowledge capital. These included:

Participating in a nationally funded research project (albeit not "engineering research" which in the national context is seen as the most important in terms of career progress).

Recognition within the engineering school as doing something related to teaching and learning.

Opportunities for members of the team to speak, correspond and share ideas with international colleagues in the field of EER from a range of international institutions which included the University of North Carolina, the School of Engineering Education of Purdue University, Bucknell University, Universidad Politécnica de Madrid and Universiti Tun Hussein Onn Malaysia.

**Resources (structural capital)**

Participating in a community or network gives one privileged access to certain resources. This includes specific pieces of information, documents, tools and procedures, but also increasingly networked information sources, tag clouds, mindmaps, links and references, search capabilities, visualization tools, and other socio-informational structures that facilitate access to information. In this case the artefacts included:

• The LAMM instrument for classroom observation
• Papers and posters (in English) produced and published in international conferences
• Power-point presentations (in Portuguese) produced collaboratively by team members for the in-house pedagogy sessions

**Collective intangible assets: reputational capital**

Over time, a successful community of practice will gain a reputation as a place where important knowledge is being produced. This reputation can give the community some authority in its field and a new voice in organizational contexts. Such reputation and authority in turn increases the legitimacy of individual members as practitioners. Examples included:

• Group members invited to speak and represent the engineering school, institution in national and international events (e.g. International Week, Quality Assurance conference);
• Invitations to group members to speak at other national institutions;
• Invitations to group members to speak at international institutions (Spain, Malaysia, Thailand and Australia).

**Brokering knowledge of the learning process: learning capital**

An additional value of being part of this community is that people are learning to learn in new strategic ways that will hold good across other contexts. Examples were:

• Learning about research funding proposals;
• Learning about research conference participation and organization;
• Learning about the use of learner activity as a learning proxy in lecture classes
  (Use of learner activity as a learning proxy in lecture classes (Williams and Carvalho 2010))
• Learning about submission of research articles (in English) to international journals.

**Cycle 3 Applied value (changes in practice)**

It is useful to follow the value of the learning of the community as members apply their knowledge to their practice in their own context: how do members of the group leverage that knowledge capital as they adapt and apply it to specific situations in their practice? Some examples follow:

One member of the community used the reputational and knowledge capital acquired during the project to build partnerships with national technology firms who are recognized innovation leaders and this in turn led to new lines of research, research partnerships with two international universities and a nationally funded research grant in the field of engineering practice (Williams and Figueiredo 2010);

Data from the interviews with participants show that all believed that the way they taught lecture classes had altered in that they integrated more active learning (AL) techniques. The Activity Index and Participation Parameter data collected in 96 observed classes during the three years supported this.

**Cycle 4 Realized value: performance improvement**

Although it may be clear that members feel more confident and are applying their capabilities in a number of ways, the ultimate test of the value of a community lies in its effects on performance and results. Performance improvement is often difficult to verify empirically but some indicators have been able to provide pointers:

LAMM data: as described above the data gathered showed learners became more active in lecture classes of participating lecturers during the period of the project and this contrasted with much lower levels of learner activity in lecture classes of traditional colleagues who had not participated. As shown in Table 1, we noted that the AL-oriented classes featured considerably more activities than the traditional ones (as we would expect) and our data showed that even when the former employed more traditional lecturing the level of student participation was also considerably higher as represented by the number of questions and answers during the class.
Assuming for simplicity that the class time recorded in column 1 of the LAMM to represent “lecturing”, Table 2 shows a comparison between the % time engaged in lecturing for both AL-oriented and traditional lecturers in our study (Williams and Carvalho 2010).

<table>
<thead>
<tr>
<th>Lecturers</th>
<th>Activity index</th>
<th>Participation parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALP oriented (n = 92)</td>
<td>45.39</td>
<td>17.1</td>
</tr>
<tr>
<td>Traditional (n = 15)</td>
<td>30.2</td>
<td>9.5</td>
</tr>
</tbody>
</table>

This tallies with findings by Cox and Cordray who used the VOS observation system to study 28 bioengineering courses in the US that “although courses are designed to be innovative, the dominant pedagogical practice is still lecture”;

Student data: pre-post test data on student expectations, subject level evaluation marks and student attendance data are being calculated at subject level and results so far do indicate a positive evolution in all three in the AL classes monitored (Neto et al 2009, 2010, 2011);

Instructor self-efficacy data: all but 2 of the participants indicated at the outset that they had no training in pedagogy and did not feel able to make a presentation to peers about such a topic. At the end of the first year all of them reported in interviews that they felt sufficiently secure to be able to make a presentation about pedagogy to peers and subsequently all members did go on to run one or more peer-sharing sessions as indeed did an additional 3 lecturers who became peripheral participants in the course of the project.

**Cycle 5 Reframing value: redefining success**

In some cases, the value of a community goes beyond improved performance and results with regard to existing metrics and indicators. The learning of the community compels it to reconsider the very definition of what matters and what constitutes success. This can often lead to a recalibrating of existing metrics and indicators, and sometimes to entirely new ones.

The original goals of the project could be summarized as the creation of the LAMM tool, 6 conference papers, 2 journal articles and dissemination to other institutions. The first two have been achieved the third was not achieved during the project lifetime, but is forthcoming, while the final objective has not been fully realized to date.
However, on approaching the end of the project it was as we wrote up the formal report for the funding agency that it started to become obvious that a broader framework was needed to capture more effectively the value created and hence it was only in the final stages that the Wenger framework began to be used.

**Discussion**

Overall the Wenger framework appears to have been useful as a tool to capture the value produced by this particular project and the authors believe it can be recommended for other researchers confronting similar issues. For value-capture purposes we believe it is clearly more appropriate than the Four-Player Model proposed by Kantor and Lehr. On the other hand, if one needs a framework which focuses more on the dynamics between the group members and how this may affect change introduction, the latter framework handles this well (Venasup et al 2009) whereas the Wenger approach does not give it prominence.

**Conclusions**

To capture the value of an EER project we describe how we have adapted a five-cycle assessment framework developed by Etienne Wenger for learning communities. We believe this framework captures the value of this type of research more comprehensively than more traditional indicators like research output and for this reason it can be useful both for preparing return on investment reports for administrators and for planning new research projects. This being said, it is to be recommended that such a broad value assessment framework be defined from the outset so as to get the benefit from continuous reflection and if necessary re-design throughout the process – if we had done this at the outset we could probably have reaped more benefit from the approach.

Although the project in question has now formally come to an end, we intend to continue monitoring its outcomes over time using this approach and hope to be in a position to publish a more detailed value report in the future.

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An Examination of Learning Strategy, Interest, Intention and Academic Performance: Case Studies of Australia and Malaysia

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Abstract: High attrition rates in engineering program are a concern worldwide. We are exploring the hypothesis that conation is an important factor for success in engineering study. This ongoing PhD research project is exploring cognitive, affective and conative elements using the Theory of Reasoned Action (TRA) model, which proposes a logical progression from cognitive through affective and conative to performance. The three elements were examined in the form of learning approaches namely learning strategy, learning interest (motive) and learning intention respectively. Participants consisted of 122 Australian students and 136 Malaysian students who completed a background questionnaire, the Study Process Questionnaire (R-SPQ-2F) scale and the Learner Autonomy Profile (LAP-SF) scale. The data analysis shows strong interrelationships between learning strategy, learning interest and learning intention. However, results in the multiple regression analysis revealed that the combination of the three learning factors did not strongly predict academic performance of the participants at both locations. Gender difference was found which revealed different learning preferences patterns between the Australian and Malaysian participants. Results are being further explored using semi-structured interview. In light of the demands for increased participation in higher education in many countries, it is important that we better understand what leads to good academic performance in engineering if we are to address the high levels of attrition that occur at many universities.

Keywords: cognitive, affective, conative, academic performance, Theory of Reasoned Action

Introduction

Over the past 20 years, a huge amount of research has been conducted in various fields and locations to explore success and attrition factors of undergraduate students at
university (e.g. Marra, Rodgers, Shen, & Bogue, 2009 & Bogue, 2009; Matusovich, Streveler, Loshbaugh, Miller, & Olds, 2008; Seymour, 1995). Higher attrition rates in engineering is also the prior concern of the current study thus embarking on our research motivation to understand factors that leads to students’ success in engineering study. Problem arise when the solutions often leads to confusion and remains unclear. The greater concern in engineering is when the number of students dropping out from the course increases from year to year (Baillie, 2000).

One problem that emerges from previous research is the lack of theory used to support their research findings. The Theory of Reasoned Action (Fishbein & Ajzen, 1975) is used as a conceptual framework in this research. The theory suggests a causative relationship between cognitive, affective and conative elements to explain the reason for specific behaviour or action. In this theory, it is assumed that beliefs about future benefits, such as a well paying engineering job, leads to desire and intention to study engineering. In this research, the TRA model is used as a guideline to discuss findings on the relationship between learning strategy (cognitive), learning interest (affective), learning intention (conation) and academic performance. Several researchers that tried to used the theory to explore academic performance or achievement failed to achieve their objectives as the model was originally developed to measure performance of a single behaviour (Fishbein & Ajzen, 1975). In the current study, cognitive, affective and conative factors were represented by learning strategy, learning interest and learning intention respectively. The three learning factors were hypothesised as predictors of academic performance in engineering course, with higher level of the three learning factors being hypothesised to contribute to higher achievement in engineering.

**The Theory of Reasoned Action**

The theory of reasoned action (TRA) is widely used in social science, psychology and medical based research to understand and predict human behaviour. It is a theory that considered the cognitive, affective and conative elements in a structured way thus being selected to be used in the current study. The theory suggests that a person’s beliefs (cognition) and attitudes (affectation) influence their intentions (conation) of performing a specific behaviour towards an object, event or activity. In the context of this study, learning strategy, learning interest and learning intention measures are used as a causal factor of academic performance. The TRA theory is used in this study as a framework to understand the ways in which learning strategy, learning interest and learning intention correlate with each other and to know whether the measured learning factors also affects on academic performance of the participants.

![Figure 1: The Fishbein and Ajzen (1975)'s Reasoned Action Theory](image-url)
The Learning Strategy, Learning Interest and Learning Intention

The first construct of the adapted theory (Figure 1), cognition is considered here in the form of learning strategy. Learning strategy describes the way students use their cognitive abilities (e.g. thinking, memorising and acquiring knowledge) as well as other academic skills (e.g. reading, problem solving, computer skills, math ability and study skills) while engaging themselves with learning processes or learning activities. Lotkowski, Robbins, & Noeth (2004) studied success factors among higher education students in the United States. The findings revealed that a combination of cognitive factors, self-confidence and motivation to achieve success (all of which are internal) were the strongest predictors of academic performance whereas a combination of cognitive factors, self-confidence, academic goals (commitment to obtain an academic degree) and external supports (e.g. institution, peers, and faculty) were the strongest predictor of persistence.

In the second construct of the framework, affection is represented by learning interest. Interest can be linked to a person’s motivation of behaviour. Motivation can be classified as either internally and/or externally driven. Intrinsic motivation (e.g., interests, feelings and emotions) influence a person from the inside, whilst extrinsic motivation refers to motivation that influences a person from the outside (e.g., reward and learning environment). While dealing with feelings and emotions, a student may react positively or negatively based on personal needs as well as external influences which may come from family member, friends and learning system. Brainard & Carlin (1997)’s research found that a student who has high interest to pursue engineering decided to drop out after several years due to loss of interest, low self-confidence and failure to adapt to the new system (university). Realising the importance of understanding students’ attitude towards learning, Koballa & Glynn (2007) explicitly discussed the role of attitude in determining a student’s achievement in science education. Since learning practices between science and engineering are very similar, these explanations may be useful for researchers to get a clearer insight about the connection between attitudes and learning outcomes in an engineering context.

The final construct in the framework, conation is represented by learning intention. The understanding of conation has expanded since it was proposed by Alexander Bain in 1859. Bain (1859) defined conation as the will or spontaneity of action that is controlled by feelings. Conation mediates connection between feeling and action. Riggs & Gholar (2009) highlighted six attributes as the fundamentals of conation: belief, courage, energy, commitment, conviction, and change. Confusion exists here when the beliefs attribute is linked to the cognitive element in the TRA model. The intention is redefined in this study as a conscious action associated directly with desire, persistence, resourcefulness and initiative to persist and succeed in engineering study. Students with high conative capacity are believed to have the ability to decide, commit and act independently (Reeves, 2006) and should actively participate in the learning process. Gerdes & Stromwall (2008) and Riggs & Gholar (2009) explain the conative domain in detail.
Methodology

Participants

Questionnaires were collected from 122 final year undergraduate students at The University of Melbourne, Australia and 136 final year undergraduate students at the Universiti Tun Hussein Onn Malaysia. The participants were enrolled in Mechanical, Electrical or Civil engineering programs at both universities. The participants are assumed to be successful in the engineering study since they have already completed 80% of the course. The same participants were invited to share their learning experiences throughout the course through interview.

For a medium effect size of .30, power of .80, and a significant value of .05, a minimum of 85 participants was needed to perform Pearson correlation analysis (Cohen, 1988; Cohen, Cohen, West, & Aiken, 2003). For the same effect size, a minimum of 116 participants were needed to perform multiple regression analysis. Therefore, the numbers of participants used in this study are considered sufficient to examine the magnitude of the relationship of the measured variables.

Instrument

In this study, strategy and interest were measured using the latest version of the learning orientation instrument (R-SPQ-2F) scale which was developed by Biggs, Kember, & Leung (2001). The R-SPQ-2F scale was an adaptation of the initial learning orientation instrument which was based on Biggs’ proposal (J. B. Biggs, 1987) on how people approach learning. According to Biggs (1987) there are three ways a student may choose to approach their course namely, a surface approach, deep approach or the achieving (strategic) approach. In the latest version of the R-SPQ-2F, only the surface approach and the deep approach items were maintained while the achieving approach items were removed. With the purpose of measuring the internal driving factors that influence students’ learning intention, only the deep strategic and deep interest scales were used to measure both learning factors in this study while the surface approach items were excluded as they are usually linked to an external driving factor (J. Biggs, Kember, & Leung, 2001; Fowler, 2003) such as goal achievement. The deep strategic and deep interest scales have five items each and reliability estimates of $\alpha = .77$ and $\alpha = .70$ respectively based on the Cronbach Alpha method. Participants were asked to answer on a Likert-type frequency scale, from 1 (never) to 5 (always).

To assess the intention, this study used a 66-item Learner Autonomy Profile-Short Form (LAP-SF) developed by Confessore & Park (Confessore & Park, 2004). The instrument measures four conative constructs: desire, resourcefulness, initiative and persistence. Participants indicated their responses on a 10 point scale, ranging from 1 (will never perform the behaviour) to 10 (will always perform the behaviour). These responses were scaled to by dividing by two to keep the response values in the same range as those from the R-SPQ-2F scale (1 to 5). A high internal consistency was derived for this study with Cronbach alpha of 0.96. The LAP instrument appeared to be the most suitable instrument.
for measuring the intention factors as it is frequently used to assess learning behaviour associated with learner autonomy.

Results

Analysis of Correlation Coefficient

Results of the Pearson correlation coefficient analyses are shown in Table 1. The interpretation of the strength of the relationship among variables is made with reference to Cohen (1988) and Cohen, Cohen, West, & Aiken, (2003).

Table 1: Person Correlation analysis (MY, N=136; AU, N=122)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Strategy</th>
<th>Interest</th>
<th>Intention</th>
<th>UCGPA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MY</td>
<td>AU</td>
<td>MY</td>
<td>AU</td>
</tr>
<tr>
<td>Strategy</td>
<td>1</td>
<td>1</td>
<td>0.774*</td>
<td>0.692*</td>
</tr>
<tr>
<td></td>
<td>(.00)</td>
<td>(.00)</td>
<td>(.02)</td>
<td>(.02)</td>
</tr>
<tr>
<td>Interest</td>
<td>1</td>
<td>1</td>
<td>0.593*</td>
<td>0.455*</td>
</tr>
<tr>
<td></td>
<td>(.00)</td>
<td>(.00)</td>
<td>(.05)</td>
<td>(.01)</td>
</tr>
<tr>
<td>Intention</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.593*</td>
</tr>
<tr>
<td></td>
<td>(.00)</td>
<td>(.00)</td>
<td>(.03)</td>
<td>(.00)</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 level (2-tailed)

It is apparent from Table 1 that strategy, interest and intention have a statistically significant and positive correlation with academic performance (UCGPA) of Australian and Malaysian students. There were also positively strong and statistically significant correlations between strategy and interest ($r_{MY} = 0.774$; $r_{AU} = 0.692$), strategy and intention ($r_{MY} = 0.542$; $r_{AU} = 0.420$), and interest and intention ($r_{MY} = 0.593$; $r_{AU} = 0.455$). These findings were consistent with Riggs & Gholar (2009)’s point of view that the cognitive, affective and conative domains are closely interconnected and interdependent.

Analysis of Multiple Regressions

The theory of reasoned action (Fishbein & Ajzen, 1975) was used as a framework to test whether learning strategy, learning interest and learning intention can predict academic performance of engineering undergraduates in Australia and Malaysia. The three predictor variables were inserted into the regression model using enter method of SPSS. The results obtained from the multiple regression analysis are presented in Table 2.

Table 2: Results of Multiple Regression Analyses (Enter Method)

<table>
<thead>
<tr>
<th>MODEL</th>
<th>Independent Variable</th>
<th>Dependent Variable</th>
<th>Australia (N=122)</th>
<th>Malaysia (N=136)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Beta, $\beta$ (p value)</td>
<td>R Square</td>
</tr>
<tr>
<td>1</td>
<td>Strategy</td>
<td>UCGPA</td>
<td>-0.181 (.14)</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td>Interest</td>
<td></td>
<td>0.148 (.24)</td>
<td>0.128 (.19)</td>
</tr>
</tbody>
</table>

*Significant at the 0.05 level (2-tailed)

Results in Table 2 shows that despite strong relationships between strategy, interest, intention and academic performance, results of the multiple regression analysis reveals
unexpected outcomes. The three learning factors only predict about 3.2% of the academic performance variance ($R^2 = 0.032$) for Australian and 8.9% ($R^2 = 0.089$) of academic performance variance for Malaysian students. For Malaysian students, the only significant variable is strategy ($\beta_{MY} = 0.398$) while for Australian students, there is no significant predictor variable for academic performance. Such results do not necessarily discount the importance of learning strategy, learning motive and learning intention to predict student’s academic performance in engineering. The next hypothesis is that the differences between male and female students’ approach towards learning contributes to such results. A backward multiple regression analysis was performed to remove any weak predictor variables in the model. The results are shown in Table 3.

Table 3: Results of Multiple Regression Analyses (Backwards Method)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Australia (N=122)</th>
<th></th>
<th>Malaysia (N=136)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R$</td>
<td>$R^2$</td>
<td>F-ratio (p value)</td>
<td>$R$</td>
</tr>
<tr>
<td>Strategy, Interest, Intention</td>
<td>0.315</td>
<td>0.100</td>
<td>3.278 (.03*)</td>
<td>0.338</td>
</tr>
<tr>
<td>Interest, Intention</td>
<td>0.309</td>
<td>0.096</td>
<td>4.764 (.01*)</td>
<td>0.296</td>
</tr>
<tr>
<td>Interest</td>
<td>0.272</td>
<td>0.074</td>
<td>7.254 (.01*)</td>
<td>0.220</td>
</tr>
<tr>
<td>Strategy</td>
<td>0.500</td>
<td>0.250</td>
<td>2.781 (.06)</td>
<td>0.377</td>
</tr>
<tr>
<td>Strategy, Interest</td>
<td>0.500</td>
<td>0.250</td>
<td>4.337 (.02*)</td>
<td>0.375</td>
</tr>
<tr>
<td>Intention</td>
<td>0.458</td>
<td>0.210</td>
<td>7.158 (.01*)</td>
<td>0.371</td>
</tr>
</tbody>
</table>

Table 3 show results of multiple regression analysis (backward elimination) based on gender function in the two locations, Australia and Malaysia. The selected regression model (as highlighted) suggesting that the learning factors found are comparable between gender in the two locations.

In Australia, learning was interest the most significant variable to predict male students’ academic performance ($R^2 = 0.074$, $F(1,91) = 7.25$, $p<.05$) while learning intention was the most significant variable to predict female students’ academic performance ($R^2 = 0.210$, $F(1,27) = 7.16$, $p<.05$). This seems intuitively appealing. Females are assumed to choose engineering quite deliberatively, while male students are assumed to follow their interests into a typical male-dominated field.

In Malaysia, learning strategy was found to significantly predict female students’ academic performance ($R^2 = 0.138$, $F(1,71) =11.354$, $p<.05$) as well as Malaysian male students although the factor was not as significant for the males ($R^2 = 0.048$, $F (1,61) = 3.097$, $p>.05$). The results seem to suggest that higher level of learning strategy contribute to higher achievement for Malaysian engineering undergraduates.
Discussion

The results demonstrate strong correlations between strategy, interest and intention thereby highlighting the importance of learning intention to integrate with learning strategy and learning interest in the engineering learning process. Each learning factor was also found to be reasonable predictors of academic performance of Australian and Malaysian engineering undergraduates students, particularly for the female students in both countries. The increasing use of technology in learning, seems to imply the need to combine learning strategy, learning interest and learning intention attributes (such as initiative and resourcefulness) if we expect students to become independent learners. The combination of the three factors are seen equally important to develop students’ personal qualities and attributes that can help stimulate their internal potential to succeed in engineering.

The multiple regression analysis shows unexpected results which revealed that the causative combination of strategy, interest and intention was not a good predictor of academic performance at both locations. Thus the finding do not support TRA model. Results were essentially changed after gender were taken into account. Four different learning patterns emerging as the results thus suggest different learning approach preferences by each group in each location. In addition, combination of two of the learning factors also significantly predicted academic performance. Findings from interviews can help explain the results of analyses.

Affection factor is increasingly seen to be important in an individual success in study (Diseth & Martinsen, 2003) however, learning interest does not explain any variance of academic performance for females students in Australia. Having deep interest in engineering topics and being attracted to learning material seems helpful for Malaysian and Australian males to engage themselves in the learning process. A typical comment from one of the interviews is:

"The real stumbling point if you are not in the mood to study or you not..I guess, if it isn't like.. if you don't get super interested in learning for example about differential equation, you're not going to sit down and put an extra time on it." [AC(M)-I7Q2-101012]

On the other hand, learning intention was found to be the best predictor of academic performance for female students in Australia. In other words, female students who have higher level of desire, resourcefulness, initiative and persistence are likely to achieve higher CGPA marks.

"The challenges that you went through, the harshest. Even it strengthens you step by step. I used to strengthen it very much. Regardless...like through anything. I don't have any feelings. I will do it. I just go through it. That's how university got to be and that what means by independent" [AE(F)-I1Q3-091118]

The single best predictor of academic performance for both genders in Malaysian samples was learning strategy which includes several strategies such as maximise understanding, optimise use of lecture notes and meaningful discovery on topics learned.
“When I did industrial training, I got chances to see the real things (engineering applications). I can see how the boiler or steamer works. So, when I did experiment in laboratory, I can easily predict what will happened next... It’s the same when I learn the related topics. I can easily relate the theory with the related application and processes. It’s just easy to learn everything once you know the real process.” [MM(M)-I1Q2-100326].

“We needed to grasp the whole concept of it and tried to relate it to our day-to-day life. That way helps me to understand more about engineering. For example, heat transfer can be applied directly to cooking tasks. With this example, I could see the benefits of learning the subject matter. I think, the understanding of concepts are important for a person to succeed in this field. [MM(F)-I4A2-101213]

The interview data also imply that students possess different learning approaches to persist and succeed in engineering. In view of the comparable results, greater attention should be paid to the differences in learning between the gender. The results would seem to suggest that there may be some cultural differences in learning. Many researchers have provided model of cultural differences in learning between Australia and Malaysia, one of them is collectivist and individualist (Hofstede, 1986). Further analysis of the results is needed to draw further conclusion.

Conclusion and Future Research

In general, the current findings suggest that the theory of reasoned action model may not be suitable to measure academic performance or achievement. The reason may be because the theory was originally developed to explain the reason of a single behaviour of a person. The complexity in the engineering learning process is that it involves anticipation of various factors such as internal and external motivation, multiple intention and continuous development of cognitive and critical thinking processes. It is seen necessary to also consider external motivational factors that can reinforce their internal factors. Combination of the internal and external factors will provide useful information for researchers and educators to better understand factors that contribute to student success and persistence in engineering. Despite providing a useful framework of elements to explain behaviour, the model may not be suitable to be used for predicting engineering learning success. Therefore, this study suggests a need for a different model structure that can explain students’ learning experiences in engineering. The gender and cultural differences in learning observed in this study should be a part of such model.

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Conference, reviews and conservations about improving engineering education

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Abstract: Peer reviews are supposed to ensure the quality of published work and are also
applied to conference papers with the same aim. But numerous studies have demonstrated
that reviews cannot be considered objective or reliable. Even if they were they do not provide
the opportunity to refine and develop ideas that conferences such as REES promote. We
began by examining how well reviews of papers submitted to the 2010 conference of the
Australasian Association for Engineering Education helped authors to improve and found
them to be often inadequate. The literature reveals that this is true for peer review generally.
We conclude with some suggestions for how ideas might be shared, developed and
disseminated through scholarly conversation while avoiding most of the pitfalls of the review
process.

Context: what do we get out of conferences?

It has been said that peer reviewed papers are a kind of “conversation in slow motion”
(Origgi 2010) which regulates the quality of scientific work and disseminates ideas. For
many of us, conferences are a stage on the road to publication which offer one way to try
out ideas before too much is invested in them, and to speed up the conversation. From the
point of view of the community in our field of engineering education, where the members
are primarily trained in engineering rather than education, conferences are important
places to share strategies and to encourage more systematic and wellgrounded research.
The importance of the conversational function of conferences has been acknowledged in
previous REES meetings through an emphasis on using sessions for discussion rather than
presentation. But the use of such discussions for improving practice and refining
knowledge carries with it a significant gatekeeping dimension. Who gets to decide what
topics are worth raising, what methodologies are considered valid and what voices should be heard? As we know, this is the function of peer review, where those who are deemed to have expert knowledge in the field regulate acceptance or rejection. But as we are all well aware, the flaws in such a system include the potential exclusion of new ideas and approaches and the reduction of a field to endless repetition of what is already well known. It can be difficult to try out new ways of thinking that don’t match current orthodoxy or to import ideas from other disciplines. This is particularly unfortunate in the case of conferences, where face to face real-time conversation is actually possible, if ideas can get over the initial hurdle of being allowed into the conversation.

For well over a decade there has been substantial disquiet over the adequacy of peer review as a mechanism to regulate scientific enquiry (Goodstein 2000) with some studies suggesting that on any measure, peer review fails to improve manuscripts and disseminate important research findings (Fitzpatrick 2010, Lipworth and Kerridge 2011). There are now international conferences on the subject of peer review (see for instance www.iiis2011.org/wmsci/Website/AboutConfer.asp?vc=27) and its inadequacies. Even if peer review did have the capacity to improve scientific conversation, it would be a rather one-sided conversation, since authors have limited right of reply. The review process does not really allow for the conversation to change ideas on both sides, but is more often a hurdle to be overcome. We are of the opinion that work in our field can be improved by conversations, debate and publication, but we want to know what role peer review fulfills currently and we want to consider what kinds of mechanisms are likely to maintain and improve standards while allowing the conversation to go on. Finally we want to consider how such mechanisms might be instituted in this community of engineering education research.

Frameworks: Epistemological considerations

Fitzpatrick (2010) points out that the peer review process for published work is based on the implicit assumption that one or two reviewers can decide on the truth or otherwise of what is submitted. She is of the opinion that the authority and prestige conferred by this assumption undermines reviewers’ ability to exercise what Origgi (2010) calls “epistemic vigilance”; a reflexive and critical stance on the reasons, biases and pressures that make some topics emerge and thrive and not others. This requires a reviewer to be aware of how their opinions, no matter how well informed, relate to the rest of the field and all possible alternatives and to take personal responsibility for their views. Yet studies which show that agreement between reviewers happens no more often than predicted by chance (Rothwell and Martin 2000, Peters and Ceci 2004) raise questions about the reliability of reviewers and their ability to maintain standards.

Nor are reviews better at developing community through conversation. Anonymity can shield reviewers from responsibility and foster half-hearted, carping and even dishonest reviews (Fitzpatrick 2010). The habit of allowing reviewers to add private comments for the editors’ eyes only further excludes the author from equal participation in the conversation.
The existence of various forms of “open review”, whereby a paper is “published” online for comment and feedback and only “reviewed” formally once a consensus has been reached on its worth, is just one alternative to existing review procedures that indicates that the way we review now is not essential to quality control (Fitzpatrick 2010). Instead of one or two reviewers having the freedom to play out their biases we need debates about what is good and interesting. Instead of a single round of comment, we need the ongoing development of ideas in conversation. We decided to allow authors in our local engineering education community to review their reviews in order to see how well the system was operating and what authors felt was helpful or otherwise.

**Methodology: Constant comparative analysis of responses to reviews**

The Australasian Association for Engineering Education (AaeE) has been actively pursuing improvement in engineering education research quality, including examination of the quality of the peer review process. For the first time at the 2010 conference authors were asked to use an online tool (SPARKPLUS) to rate the quality of their reviews and this de-identified information was discussed with delegates in an open forum at the conference.

In the analysis that follows we consider only the reviews of papers that were accepted into the “Research” category (n= 66 reviews two each for 33 papers), since clearly expressed criteria were provided for these papers and were available for authors and reviewers from the beginning of the review process. These criteria are listed in Figure 1. In this category 23 authors (70%) responded to the invitation to assess and comment on their reviews and we have considered all of these here. The online tool used to collect these assessments comprised seven questions rated on a Likert scale (strongly disagree to strongly agree - see Figure 1) but we will concentrate here on the answers to the open-ended questions, for what they tell us about what authors feel about the review process.

**Table 1: Review Criteria for AaeE 2010 ‘research’ papers**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context and research questions</td>
<td>The situation being investigated is clearly and concisely described and generates the research questions in a logical manner. The paper shows evidence of familiarity with the research literature in engineering education and where appropriate more widely. The research questions make clear what the researcher wanted to know about the situation and are questions that can generate valid and reliable answers.</td>
<td>Covers all points above but less clearly and systematically. The description of the situation may lack relevant detail OR the use of existing literature may be sketchy or tokenistic OR the questions may lack clear logical connection with the situation and literature and/or may not be susceptible of clear answers.</td>
<td>More than one of the faults referred to above.</td>
</tr>
<tr>
<td>Theoretical frameworks</td>
<td>The research is clearly situated within overarching explanatory frameworks appropriate to the research questions and the situation being researched. The concepts of the theoretical frameworks are used to structure the data gathering and/or analysis.</td>
<td>Shaky or partial links between the theory and the research questions and data.</td>
<td>No or token use of theoretical frameworks or theory that is not well chosen for the research questions. Misunderstood theory.</td>
</tr>
</tbody>
</table>
### 3. Methodology

| Excellent | The methodology describes the logic of the connection between what the researcher wanted to know and the data gathering process, making clear the strengths and limitations of the methods chosen. Well chosen and imaginative data gathering methods. |
| Good      | Adequate but limited (?pedestrian) choice of methods. Sketchy rationale. |
| Poor      | No rationale for choice of methods. Poorly chosen methods. |

#### 4. Findings and Conclusions

| Excellent | The findings are well argued on the basis of the data presented. Alternative explanations are considered and their rejection explained. |
| Good      | Good connection between data and conclusions |
| Poor      | Findings do not account for all of the data presented or are not well supported by the data. |

#### 5. Discussion

| Excellent | This section returns the reader to a consideration of the starting point of the research. It may discuss how the findings clarify the original situation of interest, throw new light on the theoretical stance taken or the methodological adequacy of the research and/or make recommendations for engineering education research more widely. Answers the ‘so what?’ question. |
| Good      | Points out the relevance of this research for understanding the original situation but makes limited reference to wider application. |
| Poor      | Fails to connect the results of the research with the wider research environment. |

![Figure 1: Likert scale questions for authors in regard to the reviews they received at AaeE 2010.](image-url)

Reviews and author responses were entered into NVivo9 and coded for recurring themes using the constant comparative method to build up a codebook for analysis. The coder had not been involved in the original review process although he had been a co-author on one of the papers submitted. He did not submit an author response and thus represents someone with experience of the community but no direct former involvement in the review process which might have biased his reading of the texts. He was trained in content analysis methods and results were discussed with the other researchers on the project when analysis was complete.

**Findings: paper review process inadequate to its aims**

Although the provision of criteria was meant to make it clear to reviewers what the expectations of the conference organizing committee were, only 4 reviewers made explicit
reference to them. Instead reviewers seemed to respond to the papers on the basis of what they decided was important (Table 2), such as grammatical errors. The lack of epistemic vigilance this indicates is embodied in the comment "There are other typo’s [sic] (e.g. 2nd last line on page 5 – leaning should be learning)." A reviewer who can point out typographical errors while making one has not, in our view, stopped to reflect on their own role, even if they are used to commenting on language usage as a result of some journals’ requirements for reviews.

Table 2: Categories of explicit advice given by reviewers AaeE2010

<table>
<thead>
<tr>
<th>Type of advice</th>
<th>No. of reviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaps in logic</td>
<td>39</td>
</tr>
<tr>
<td>Typographical/grammar errors</td>
<td>34</td>
</tr>
<tr>
<td>Inadequate data handling</td>
<td>27</td>
</tr>
<tr>
<td>Identifying relevant literature</td>
<td>17</td>
</tr>
</tbody>
</table>

A further feature of these reviews was lack of specificity. Relatively few (17 out of 66) pointed out where authors might go in the literature to improve their argument, and only 12 quoted from the paper under review to make clear either what was wrong or how it needed to be corrected. If the aim of review is partly to improve practice, then reviewers need to be specific about how to do so. Authors who took the opportunity to make open-ended comments about their reviews also identified this (Table 3) as a failing in the reviews (Willey et al. 2011). Counterproductive reviews were those which discouraged authors by not giving advice and ineffectual ones were those which failed to meet the authors desire to improve their work by commenting on how this might be done.

A further distancing of the reviewers from the authors can be seen in their mode of address. When referring to themselves reviewers most often used the first person (sometimes in the royal plural) but occasionally using third person forms such as “the reader”, as common practice in some fields (erroneously thought to be more objective) requires. 24 of the reviews avoided referring to themselves at all, giving a God’s-eye depersonalized opinion. In addressing the author third person forms “the author should consider…” predominated over second person “you should...” English conversation does not allow for the use of third person between interlocutors, so we have to assume that this is not being treated as a conversation by the reviewers. In addition the distancing implied by the depersonalized forms is another indication of a lack of epistemic vigilance since the first condition of self-reflection is self-awareness. A reviewer who refers to themselves in
the third person (or not at all) is not offering an opinion but expressing a truth, and this we know they cannot do.

**Recommendations: possible alternative procedures**

Peer reviewed publication is a process of central importance to scientific inquiry. It is a process that is the standard method of communication allowing researchers to inform others of their work, and a process by which a conversation between researchers occurs (Origgi 2010). Peer review also performs a gatekeeping function, supposedly ensuring quality research is published (Lipworth & Kerridge 2011; Fitzpatrick 2010) and thereby improving the quality of research. The problems we have identified here relate to the adequacy of peer review for these purposes. We especially question the relevance of applying standard norms of peer review to conference presentations which ought, we contend, to foster conversation and debate. The discussion of peer review for publication offers us some alternatives that might usefully be applied to conferences.

The model suggested by Fitzpatrick (2010) is that of peer-to-peer social media. In electronic media there is no scarcity of space and thus no rationale for filtering before publication. Instead, an arena is created where everything can be accepted and the participants in that space either take up the offering or not, help refine it through debate and disseminate it around the community. This is filtering by the many rather than the few and examples exist of such systems working in science and engineering (the arXiv repository for instance, Fitzpatrick 2010). The examples Fitzpatrick discusses may or may not go on to paper publication but such a space could also be productive in raising the quality of conference discussion. Review of abstracts or papers could be replaced by online discussion. Over some weeks that discussion would identify the issues of most interest to the community. The conference could then be organized around discussion sessions on those themes. This is similar to the way REES works now but the community vets the discussion, not a few fallible reviewers. There is ample evidence that such processes actually raise the level of debate as long as a few basic principles are adhered to. The forum must not be manipulable by a few gatekeepers. Participation must reach a critical mass and for most academics that means it must be built into institutional reward systems. We have to start arguing that this kind of activity be included in the impact measures of our work. And finally there has to be some quality control - but of participants not submissions. Fitzpatrick (2010) suggests this may be done by participants vouching for newcomers.

Attendance at conferences is a valuable part of developing ideas because it allows for conversation and debate. The review process can tend to limit such debate, and this is particularly unfortunate in an interdisciplinary field such as ours. We look forward to discussing the alternatives we have put forward here with you.

**References**


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Topic: Teaching & Learning 5 – Chair: Gregory Light

The answer to an exercise, the answer to a project: The teaching of creativity and project decision taking in the field of structures

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Abstract: Engineering design is a creative task. Starting from this idea, the paper addresses the issue of how to deal with teaching structure design while reinforcing its formal and compositive potential. The analysis develops from the notion of creativity as a process, and on the parallelism between the creative problem solving and the scientific and architectural design methods, extending it to the specific field of structural design. Newby’s and Happold’s proposals of structural design processes are considered to identify the main steps and specific characteristics of the design of a structure which allow and encourage creative development, in order to implement them in classroom exercises. From this analysis and two classroom experiences briefly presented, the paper proposes the reproduction of the real design process of a structure, from competition to concept and detail design, as a challenging exercise to students, involving both creativity and project decision taking tasks.

Introduction – Engineering is not a science, the creativity of engineering

"Engineering is not a science. Science studies particular events to find general laws. Engineering design makes use of these laws to solve particular practical problems. In this it is more related to art or craft" (Arup, 1968). This statement is supported, in the field of structural design, by two key aspects: the indeterminate nature of the structural problem, and the formal and compositive potential of the structure itself.

On one hand a project design or structure system does not have a solution in itself; or rather, there is not just one solution, but a range of possible answers, the evaluation of which depends on both objective criteria (structural efficiency, ease of construction, cost...), and subjective criteria (formal, appearance, composition...). Structures are not an exact science, nor do project designs constitute a determinate and precise map of what needs to be done; rather they provide a subjective element in the choice of a particular option from among the different possible alternatives.
Secondly, all structures have a determinate physical reality, and this corporeity affects the space which it occupies to a greater or lesser extent, as it can hardly remain aloof or indifferent to the presence of a new structure. Therefore the structure is not a silent element in the project design, but one which necessarily has a relevant role in the spatial layout. This is clear in the case of a bridge, the presence of which inevitably alters the surrounding landscape, but is also true of buildings, in which a small alteration in the even distribution of columns, for example, radically changes the perception of space (Fig. 1).

This thought results in a radical change in the conceptual and project design understanding of the structure: structural elements are not only able to ensure the stability of the building, but can also play a key role in the definition and configuration of the surrounding space, adopting a relevant conceptual and creative dimension (Bernabeu, 2010).

Starting from this idea, the paper addresses the issue of how to deal with teaching structure design while reinforcing its formal and compositive potential. In order to do so two recent teaching experiences, both at the School of Architects and Engineers in Madrid, are presented. These teaching experiences were proposed taking into consideration the existing framework, experiences and principles in the development of creativity in engineering and the processes which govern it, in addition to the personal professional experience as structure designers of the authors. The purpose is to suggest exercises and work methods which involve students in the formal and compositive consideration of the structure and in the decision making process, thus encouraging creativity.

The creative process versus the structural design process and the process of solving an exercise

Creative and structural design processes

The study works on the notion of creativity as a process and the evaluation of the stages and elements which govern its development, in addition to comparison with the processes which define the design and development of the structure for a project. In this sense, the classical four steps in creative problem solving, as specified by Wallas, are considered - preparation, incubation, illumination and verification- (Wallas, 1926), and in particular the parallelism between these stages and the scientific and engineering decision methods proposed by Santamaria and Akhoundi (Figure 2).
In accordance with the above parallelism, the different processes start with an initial preparatory stage, consisting of study and data compilation, which may seem a tedious and unimportant task, but which is nevertheless crucial for the subsequent creative development of the process. The next stage is the study of this data, and the developing of possible solutions, after which a new idea or solution can be addressed, finally validated in the final assessment and verification stage.

Going forward to this parallelism, a resemblance with the design process in the specific field of structural design might be done, in order to identify which aspects of this process are most important from a creative development perspective. In this regard it is necessary to first evaluate the different existing structural design methods and processes, clearly defining the concepts and characteristics of the process in question.

This study thus establishes as the principal of analysis the structural design processes proposed by the engineers Frank Newby and Edmund Happold, with a diverse focus and which are particularly significant for assessing the structural development process and highlighting the key aspects in terms of compatibility and relation to the creative processes.

Firstly, Frank Newby proposes a design process for the structure which is similar to the parallelism of processes proposed by Santamaria (Addis, 2001). It first lays out the “initial design process” which takes as a starting point the particular structural conditions of the project (availability of material and workmanship, weather and geotechnical conditions, local regulations...), in addition to the client requirements and the architectural concept of the project.

Based on that initial stage of data compilation and establishing of the fundamental figures, the engineer considers possible structural layouts and progresses in the definition, integration and coordination of the chosen scheme, and in the detailed definitions of the different elements contained in it, using his/her own knowledge and experience in the use of materials and the analysis of structures as a benchmark (Figure 3).
On the other hand, Edmund Happold’s design process is presented as an alternative to the traditional cyclical system, which establishes a series of phases (analysis, synthesis, evaluation and communication) which are repeated in the different stages of the process, delving deeper into the definition of the project in each cycle (Happold, 1976). However, Happold proposes a step by step system, which he calls “convergent”, and which consists of successive four stages, meaning that each stage is not reached until all the objectives of the previous stage have been met, which is checked using a system known as Merit Control, a continuous control mechanism, looking ahead to possible future requirements or developments, and looking back at the objectives (Figure 4). A significant example of this method is the roof structure for the Manheim exhibition hall, by Frei Otto and Ove Arup & Partners.

This process is not contrary to the four stages of the creative process, although it presents some issues which may differ from other creative processes and methods and which are fundamental in the case of structural design, and must therefore be taken into consideration in this context.

Firstly, it stresses the fact that, contrary to what tends to occur in artistic processes and certain scientific research processes, the project for a structure does not depend on, and is not controlled by a single person, but is a joint activity closely connected to the role of the architect, the client and the contractor.
Furthermore it clearly establishes an ongoing control system which should not be perceived solely in technical terms, but which also considers the formal and compositive objectives, as well as its relation and integration with the different aspects of the project (architectural, construction, functional...).

Finally, and this converges with Newby’s method, the design process is understood to be an evolving system, open and integrating. The development of the project does thus not consist only of increasing the degree of definition and detail of the different elements, but each decision can question certain previous approaches (technical or formal) and the initial shape or layout may even be altered where necessary. As the development and definition of the project progresses, the requirements and conditioning factors of the different disciplines are considered in a staggered and converging manner, and decisions made in previous phases are reconsidered where necessary.

**The answer to an exercise, the answer to a project**

Based on this study of the design processes for structure and their relation to the creative processes, the next point of analysis is the comparison of these models with the process of resolving an exercise. This phase also considers the guidelines proposed in other studies and analyses (in particular Torrance, 1977, as well as Richards, 1988 and Stouffer, 2004). The purpose is to identify the main steps and characteristics of the design of a structure which allow and encourage creative development, in order to include them or reproduce them in the exercises and work proposed to students.

The analysis completed highlights the following points:

- The study and data compilation stage (initial stage of the creative process) should form an integral part of the exercise and be assessed as such. The formulation of the exercise must only give the minimum necessary data for defining the exercise, and the student must be responsible for compiling the rest.
- Strengthening the open and evolving nature of the design of the structure, suggesting alternatives as the development of the exercise progresses, which may be included in the development or may be even challenged.
- Establishing a possible confrontation with the tutor, which reflects the relationship between the engineer and the client or the other people involved on the project.
- Addressing open and wide exercises, which require the connection and application of other structural knowledge acquired by the students.
- Proposing exercises with an open or multiple solution, encouraging a range of interpretations and evaluations, and making the decision making process an integral part of the work.
Two classroom experiences: Structure for a temporary market and International competition for a new bridge in San Sebastián

Structure for a temporary market in Madrid (E.T.S Arquitectura de Madrid)

The purpose of this exercise, proposed at the Master on Building Structures of the Architectural school in Madrid, is to design, from concept to detail, the structure of a existing project, a temporary market in Madrid. The initial data students are provided with consists of a set of the architecture drawings and a presentation of the project by the design architects (Nieto y Sobejano in this case). During this presentation the main architectural requirements and formal considerations are introduced, and students can freely ask any question or comment about the project they may have. Besides, they are also encouraged to visit the building, and to consult existing publications and articles on the project. Any other initial data (loading, ground conditions, functionality requirements, building regulations...) remains under the students' scope of work, who work in groups of two or three people.

Starting from this point, several phases and project submissions are considered, from the definition of the basis of design and the structure conception, to the structural analysis and sizing of the different elements, and finally the design of the connection details. In the first phase (concept design), students are encouraged not to reproduce the existing built structure of the project, but to propose innovative alternatives, changing the architectural shape and geometry if necessary (but preserving the architectural concept). Besides, during the design process they are also encouraged, and in some cases requested, to reconsider the initial proposed design, according to the results of the analysis undertaken (for example, the connection design of a structural element may imply a change on the sizing of the members, or even in the configuration of the structural element itself).

The teaching purpose of this exercise is to reproduce the design process of a real architectural project, encouraging the students' implication in the conception phase, and following them during the design process, with a double task from the teacher of assisting the students in pure technical issues, and playing the role of the rest of participants in the project (client, architect, contractor...), in order to discuss and challenge their proposals from their respective point of view.

The result from this classroom experience has been very satisfactory, arising a number of different possible structural solutions, and generating fruitful discussions (technical of course, but also formal and aesthetical) during the presentation sessions undertaken at the end of each phase (Fig. 5).
International competition for a new bridge in San Sebastián (E.T.S.I. Caminos, Canales y Puertos)

An international competition was organised at the Civil Engineering school of Madrid, open to a number of architectural and engineering schools in Europe. The purpose of the competition was to present, at a preliminary design stage, a proposal for a new 80-meters-span bridge over the Urumea river in San Sebastián.

The initial data the partipants are provided with are similar to those of a real competition (location, traffic requirements, water levels, clearance height required...). They are then asked to present, both in a written report and in graphical documentation, their bridge proposal, describing and defending their solution in terms of technical viability, ease of construction, cost, relation to the environment, formal considerations... In this sense they are free to propose whatever bridge configuration or structural type they think suitable to the proposed location and requirements.

From the presented works a selection of 5 is done, inviting them to present in person their proposal to a international jury formed by well-known engineers. Figure 6 shows the three winners of the competition (from Austria and from Spain), illustrating the diversity and interest of the proposed solutions.

Conclusions

The comparative analysis of the structural design and creative processes and the classroom experiences presented show the importance to transmit the understanding of the structural design as an open and evolving process, involving both technical and aesthetic requirements and conditions. Structures are not only about calculation and analysis, but first of all about creativity and design.

The reproduction of the real design process of a structure, from competition phase to concept and detail design, has proven to be a good challenge to students, involving both creativity and project decision taking tasks. Besides it promotes the specific application of structural knowledge previously acquired by the students, and it also requires their implication to defend their own design proposals (which make them conscious of the strengths and weaknesses of their proposals).
Further research currently in progress consists in the presentation to the students of the key moments and decisions during the design process of real projects in which the authors have been involved. Students are then proposed to do likewise on their own exercise, as a further analysis of the process of solving it. Besides, a quantitative review and analysis of the classroom experience at the Architectural School is being prepared, in order to clearly identify its key performance indicators, and to improve it for the forthcoming years.

References


Clasroom experiences teams


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Dealing With Ambiguity in Open-Ended Engineering Problems

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Abstract: Thirty materials engineering students solved four problems which varied in level of complexity as well as closed- and open-endedness. Students scored lower on more complex problems, but scored higher on open-ended problems. However, students who solved the problems in a think aloud setting expressed greater discomfort with the open-ended problems because of the lack of constraints provided by these problems. Students dealt with the ambiguity of the open-ended problems in a variety of ways. Some students provided ambiguous answers while others added their own constraints to the problems. The manner in which problems were scored may have contributed to the unexpected finding that students scored higher on open-ended problems.

Introduction

Open-ended problem solving is critical to engineering practice, and yet classroom instruction often does not adequately provide opportunities for students to learn the processes needed to address open-ended problems (Jonassen, Strobel, & Lee, 2006). Open-ended problems are not fully constrained and often possess multiple criteria that can be used to evaluate solutions (Shin, Jonassen, & McGee, 2003). This ambiguity, or lack of complete constraints, can lead to differences in problem interpretation between problem solvers and means that a variety of solutions are possible. Criteria used for judging solutions to open-ended problems are often subjective and as a result solutions are neither right nor wrong but are judged in terms of plausibility or acceptability (Simon, 1981; Voss, 2006). In contrast, closed-ended problems have “only one correct solution that can be determined with total certainty” (Schraw, Dunkle, & Bendixen, 1995, p. 523) Problems may also vary in complexity in addition to being closed- or open-ended.
Jonassen (2000) argues that “problem difficulty is a function of problem complexity” where complexity is determined by the number of branches at each node (or decision point) on the path to a solution as well as the depth of search required to reach a solution node.

Various authors have pointed out that solving open-ended problems requires a different skill set than solving closed-ended problems, and that learning to solve closed-ended problems does not necessarily lead to an advantage in solving open-ended problems (Jonassen et al., 2006; Schraw et al., 1995; Woods et al., 1997). While efforts have been made to create engineering curricula to help students develop skills in solving open-ended problems (Incropera & Fox, 1996; Sheppard, Macatangay, Colby, & Sullivan, 2008; Woods et al., 1997), a greater understanding of the approaches that students use in solving such problems is needed to better inform such efforts. The purpose of this study is to compare students’ solutions to both closed- and open-ended problems and to identify the processes students use when solving open-ended problems. Two research questions guided this study:

1. What are the solution scores of engineering students on both closed- and open-ended problems?
2. How do students describe the problem-solving processes they use while solving open-ended problems?

Method

This mixed-method study was conducted at a large public research university in the US. Four materials engineering problems were written to span a range of closed- vs. open-endedness as well as a range of complexity based on the number of decision points needed to reach a solution. A total of 30 third- and fourth-year undergraduate materials engineering students participated in this study. Ten of the students participated in video recorded think aloud sessions in which they verbalized their thoughts while solving the four engineering problems (Ericsson & Simon, 1993; van Someren, Barnard, & Sandberg, 1994). The remaining 20 students solved the problems in a traditional test setting. During the think aloud sessions, each participant was provided with a textbook for reference (Callister, 2007) and they were allowed to use a calculator. The video recordings of the think aloud sessions were transcribed verbatim and analysed using thematic analysis (Marshall & Rossman, 2006; Patton, 2002) to answer the second research question which asked how students describe their problem solving processes while solving open-ended problems. Transcript segments related to the problem-solving processes were identified and coded and then these codes were grouped into themes and sub-themes. Students’ written solutions were graded using a rubric that awarded points for successful completion of various steps in the solution process; this rubric was constructed to be similar to what would be used to grade exam problems in a course setting. To answer the first research question, which asked about differences in scores between closed- and open-ended problems, t-tests were run to compare the average scores for these two types of problems. Participant names used in this paper are pseudonyms.
Results

Average scores for the four problems that students solved are presented in Table 1. Average scores separated by problem type are presented in Table 2. On average students scored significantly higher on problems with few decision points (78%) than problems with many decision points (56%), \( t(1, 118) = 4.25, p < .001 \). A greater number of decision points was expected to result in more challenging problems because the problem solver would have to consider a greater number of variables while generating a solution. In contrast, students scored higher on open-ended problems (75%) compared to closed-ended problems (59%), \( t(1, 118) = 2.98, p < .001 \).

<table>
<thead>
<tr>
<th>Table 1: Average problem scores</th>
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<tbody>
<tr>
<td>Problem 1 (Closed-Few)</td>
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<tr>
<td>Average Score (Out of 100%)</td>
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<tr>
<td>Standard Deviation</td>
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</tbody>
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<table>
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<tr>
<th>Table 2: Average scores by problem type</th>
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<tbody>
<tr>
<td>Few decision points</td>
</tr>
<tr>
<td>Average Score (Out of 100%)</td>
</tr>
<tr>
<td>Standard Deviation</td>
</tr>
</tbody>
</table>

This was an unexpected finding, as it had been anticipated that students would have lower scores on the two open-ended problems. The average score for problem 3 was much higher than the average scores for the other three problems, and, in addition, the variance for this problem was much lower than that of other problems. The unusually high scores of students on this problem likely contributed to the unexpectedly higher scores on the open-ended problems. Qualitative data from the ten students who participated in the think alouds were examined to gain further insight into this unexpected finding. Although students scored higher on open-ended problems, students who participated in the think alouds expressed greater discomfort with these problems due to the ambiguous nature of the problems. Analysis of the think aloud data from the two open-ended problems resulted in three themes describing students’ responses to ambiguity: 1. Students had difficulty accessing the problems, 2. Students used various processes to deal with ambiguity, and 3. Students made decisions in various ways in response to ambiguity. Within each of these themes are subthemes which describe the kinds of difficulties that students had with accessing the problems, the processes that students used to deal with ambiguity, and the kinds of decisions that students made in response to ambiguity that they encountered in the problems.
Difficulty accessing the problems

The ambiguity found in the open-ended problem statements created a challenge for many participants as they sought to access the problems and find a starting point for their problem solving. Many students felt that the problem statements provided insufficient context. After reading one of the problem statements, Nick engaged in a process of self-questioning asking, “I don’t, well, what do I, what am I supporting? Like am I supporting wood? Or am I, what’s the weight of this platform? Does it matter?” Other students responded to the perceived lack of context by connecting the problem to a context with which they were familiar. Andrew, for example, explained, “I’m trying to think how such a bridge would be designed and I don’t see it in my head. So, truss bridge. It’s got something to do with the term truss’ which I think of as house trusses which are designed similar to this.”

After reading the problem statements many students were troubled by the lack of constraints and/or evaluation criteria that were provided to them. Some of these students believed that critical information was missing from the problem statements. After reading one problem statement, James argued, “It says it’s a thin strand, so you have to assume some kind of area for that which I’m not sure how much of a thin strand for something that can withstand that kind of force would be. They really should’ve specified that in the problem.” Daniel, in contrast, wondered if the lack of constraints was a result of failing to read the problem statement carefully, explaining, “I would still need the dimensions of the member for that and all I know is the length. Trying to figure out if I am missing something in the problem. I’m reading again.”

Several students exhibited considerable uncertainty as they approached the open-ended problems. Some of these students felt overwhelmed by the ambiguous nature of these problems. Sarah’s approach to one of the problems was to begin searching through the materials properties tables in the back of the supplied textbook. After a quick scan through the materials in the tables she exclaimed, “There’s a lot! I don’t really know where to start.” Ryan’s approach to one of the problems was similar. He explained, “It’s like a vague problem so you can really go a lot of different ways with it, so I’m just like looking at materials properties.” For other students, the feeling that they were missing something in the problem statement—as described in the previous category—was the source of their uncertainty. While solving one problem Daniel said, “Um, my plan is to try to figure out if maybe I can look through the table of contents and find something that will help jog my brain—try to get me on—because I know there’s something here that I’m missing and I can’t quite figure out what it is. It seems like I don’t have enough information to solve the problem right now.”

Processes used to deal with ambiguity

Students described using different kinds of plans, or processes, to deal with the ambiguity they found in the problems. Some students used an equation-oriented plan, or process, in response to the ambiguity in the problems. Daniel, for example, worked through the various knowns and unknowns that he encountered in one problem and searched through the textbook to find equations that he could use to relate them together, explaining, “So we
have 12 foot in length, and we need cross-section. Force. Okay, strain relates to length. Stress. Young’s modulus relates stress and strain. So, I’m going to try to play with the equations see if something comes up. Here we have... so I’m looking for stress F, ah not F. I need the strain. I’m going to take strain back to basic lengths. Hmm... I’m going to go back through the book some more see if I can find some more equations.”

Each of the open-ended problems had more than one unknown. A process that many students used to reduce the number of unknowns was to select a value for one of the unknowns and then solve for the other. This often involved selecting a material to fix material property values. Sarah provides an example of how she developed such a plan. “Okay, well. I don't really know where to start, but I guess it doesn't matter what the platform is or how many strands because it said each one will be 12,000 Newtons and the design requires a safety factor of 2. So, I think that means it needs to be able to support 24,000 Newtons. So an appropriate material for these strands and strand diameter. Well, I’m going to have to look up some materials. (Re-reading question) Um, I guess I'll look up yield strength or something. Oh yeah, I can use yield strength because then that will help me get the diameter because of force over area.”

Iteration was a tactic that some students used to deal with the ambiguity of the problems. Brandon, for instance, adjusted the safety factor that he was using for one problem in an attempt to narrow in on a solution. —Maybe we don’t have to be so safe. Maybe we can use a safety factor of 1.5. 75.5 divided by 1.5. That’s good. (Calculating) 500,000 divided by 50 times 10 to the 3 is 10 times 144, 1440 times 0.289, dang it! All right, even being less safe doesn’t help, so we need something with a (looking in book), less of a density.”

The way in which decisions were made to deal with ambiguity

Students made several kinds of problem solving decisions when confronted with ambiguity in the problems. They made both functional decisions that allowed them to move forward in the problem (“I’m going to just pick one to start with and I’m going to use steel alloy.”) and decisions that they felt would help avoid getting stuck, even if those decisions were not actually part of the problem statement (“...this is an outdoor project, we need corrosion resistance.”).

Some students made arbitrary assumptions in response to the ambiguity that they encountered. Robert explained that, —The problem with this problem is that they don’t really give you a design life expectancy, so with that you have to deal with corrosion and other things. So the design parameters are again kind of vague. So when they give you vague you assume to make it the easiest on yourself.” And James picked a numerical value for one of the unknowns that he thought might result in simple calculations, explaining, ”Just for the sake of getting this done I’m going to assume that it's, hmm, wondering what would be reasonable. Perhaps one square inch would be easy.”

Several students relied on a personal knowledge base or past experiences to inform the decisions that they made. Ryan, for example, used his knowledge to help narrow down his material choices, explaining, “Okay, so tension means that um, ceramics can’t be used no matter what because they’re only good in compression.” Other participants, such as Alex,
referred specifically to personal experience to inform their decisions. "This perhaps is another instance where I need to make an assumption. I don't have the area for this beam, but I can estimate a reasonable area... Assume 6 inches by 6 inches and this is another guess based on, I guess partially an experience of, based on what would be a reasonable width per beam based on that length because I've worked with beams before."

Some students responded to the ambiguity in the problems by providing ambiguous answers. Andrew simply specified “steel” as his material selection for one problem, explaining, "Could be made of any structural steel as they all have high modulus, it's going to be fine for that." Alex provided a range of answers for one problem, explaining, "And in that case I would recommend aluminium, and this is with a diameter of 1 mm, but we'll give a range, 1 mm to 1 cm. These will all work depending on what they want by "thin".

Students added constraints, or evaluation criteria, to the problems to aid in the decision making process. Cost was a common criterion that students used to evaluate their solutions even when cost was not specified as a criterion in the problem statements. Alex described his material choice for one of the problems in this way, "Aluminium fits the criteria without going too overboard which means the cost should be best for it as well." Another student, Ryan, added several constraints to one of the problems including material “formability”, the location of the bridge that he was designing ("outdoor project"), and “fatigue characteristics" of the material that he would choose.

**Discussion**

Qualitative results of this study appear to be in opposition to quantitative ones with students scoring higher on open-ended problems than on closed-ended ones. Students who participated in think aloud problem solving sessions, however, described considerable discomfort with the open-ended problems. The higher scores on the open-ended problems may be a result of both the way in which problems were written and the way in which they were assessed. Few constraints and/or evaluation criteria were provided in the problem statements for the open-ended problems. In addition, the rubric that was used to evaluate students’ solutions assessed solutions based only on criteria that were supplied in the problem statements. As a result students could receive full credit for solutions that met the problem criteria but were not reasonable in a real-world context. The problems and the rubric were written to mimic problems and grading practices that students might encounter in their courses. Larger and more complex design projects would likely place more emphasis on the reasonableness of solutions. Nevertheless, results reveal that a solution score may not accurately reflect the difficulties that students face in solving open-ended problems. It may be necessary for instructors to develop alternate assessment methods that take into account barriers students’ face while solving open-ended problems.

Many of the students in this study struggled with the lack of constraints provided by the open-ended problems, feeling that the problem did not provide them with adequate details or context. When students solve exam or textbook problems they have the benefit of knowing that these problems will cover the material from a particular course or chapter.
of a textbook. Students in this study were not able to make use of such context information as they did not know beforehand what contexts the problems would be drawn from.

It was surprising that some students failed to recognize that two of the problems were not fully constrained. It appears that these students may associate an exam taking environment, such as that used in this study, with only closed-ended problems. While some students felt that they were missing something in the problem, others dealt with ambiguity in a variety of ways. Some students provided ambiguous solutions while others added constraints and evaluation criteria. Experiences, whether extra-curricular or from courses, appeared to play an important role in helping students to develop such constraints and evaluation criteria.

**Conclusion**

Students participating in this study had higher scores on open-ended problems than on closed-ended problems. However, students who solved the problems in a think aloud setting expressed greater discomfort with the perceived ambiguity of the open-ended problems. The study presented in this paper is part of a larger study of problem solving which is exploring the relationships among students’ problem solving approaches, their epistemic beliefs, and measures of working memory. The discomfort that participants expressed with open-ended problems in the think aloud sessions may result from low-level epistemic beliefs in which they view all problems as if they should have a single clear solution. Follow-up interviews were conducted with participants after the think aloud sessions; analysis of data from these interviews should provide greater understanding of how students’ epistemic beliefs may impact their problem solving approaches.

The uncertainty that students exhibited with the open-ended problems may also result from a lack of exposure to such problems. The textbook supplied to participants during this study was one that all of them had used in prior courses. At the end of most chapters in the book are “design” problems. Most of these problems, however, are evaluative in nature and fully constrained. In addition to having more opportunities to solve open-ended problems, students could benefit from having to assess the reasonableness of their solutions to these problems. Peer assessments of solutions to open-ended problems could provide a means for students to give and receive feedback on problem solutions. Students could then be provided with an opportunity to respond to feedback they receive and to modify their solutions if desired. In addition, instructors could devote more time to modelling effective approaches to solving open-ended problems.

**References**


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Using case-based learning in undergraduate engineering courses

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Abstract: The convenience and effectiveness of using case and project-based learning in undergraduate courses in engineering degrees is currently a subject of debate in many academic forums. While some lecturers support the advantages of these constructive learner-centred methods independently of the topic, others are sceptical about their use, mainly when addressing the teaching of scientific or technical fundamentals. In this paper, we comment on some issues that should be considered when using case-based learning in an undergraduate engineering course: audience analysis, course organization, material preparation, session delivery, and assessment method are key points to build a satisfactory learning experience. From our understanding, using cases may be adequate to contextualize some non-technical courses, providing the students with a practical background that helps motivating the interest of, for example, management problems.

Introduction

Project-based and case-based learning are instructional approaches focused on promoting active learning. The first one (PBL) evolved from innovative health science curricula introduced in North America (McMaster University, Canada) more than 30 years ago, to facilitate students to handle medical problems by using hypothetical-deductive reasoning (Savery, 2006). Basically, from the student point of view, PBL means working on a classroom project or challenge, individually or in groups, in order to come to a reasonable solution by facing design, problem solving, decision-making and research activities. Its practical difference with respect to case-based techniques may be slight; it is usually related to the narrative method and the type of issues (contents) addressed. While project-based learning typically refers to technical problems, cases are oriented to deal with general management (strategy, human resources, operations, etc.), financial or commercial issues. The case method relies on elaborated narratives about (almost) real events, which usually ends posing a question, with no fixed solution, to be elucidated after considering the context and details of the case (Ellet, 2007). Case-based learning has been
intensively used in law and business schools since the beginning of the last century and it is also applied in corporate and industrial training (Merseth, 1991).

In both methods, the lecturer becomes a facilitator, and the group, the ecosystem for discussion and discovery.

In this paper, we are going to focus on the application of case-based learning to non-technical courses for engineering undergraduate students. For some years now, we have been using it to introduce project management problems to students in the last course of engineering degrees. We have made some changes on the traditional case method in order to adapt it to the rhythm and configuration of the course. In the next section, we summarize the key points that are relevant in the process of preparing and delivering a case-based session, in particular when considering the constraints or special conditions that may be imposed by undergraduates.

**Factors to consider when delivering case-based courses for engineering undergraduates**

The following list gathers some items that are relevant when facing the re-structuration of a course (or the creation of a new one) mainly based on cases. It is not exhaustive, but tries to retrieve the most important factors that have to be addressed.

**Teaching context**

Engineering students are not usually familiar with cases; on the contrary, in other disciplines (management, social sciences (Barraket, 2005) – e.g. politics (Hale, 2005), medicine (Williams, 2005), laws (Shugan, 2006), public relations (Parkinson and Ekachai, 2002), etc.), the use of cases (even if informal) is much more frequent, as they have a strong practice component which cannot be addressed otherwise. For this reason, the first step to facilitate the course delivery, when using cases, is to explain students in advance the methodological objective, what they are expected to do as homework and how the on-site session dynamics is going to be.

In general, when driving a case-based course, students have to work on each case at two stages. First of all, they have to assume some personal work to analyse, contextualize and solve some previous questions to understand the problem. This has to be done before the discussion session, and depending on the case complexity, it may be a time demanding task. At this stage, theoretical knowledge is to be practiced, so the questions posed for the off-site phase may focus on theory aspects that should be clear and reinforced. Apart from that, the objective of this part is to get the students ready for a productive exchange of opinions and arguments.

During the second stage, the instructor, in its facilitator role, has to lively motivate the analysis of the case, drive the session to make students share their views, generate debate on critical aspects, and lead the group towards conclusions. The instructor may use role-play, group work, or other techniques to initiate or activate the discussion.
Group profile

In the first sessions of the course, the facilitator needs to analyze the group profile, in order to adapt the session strategy to the group’s behavioral features. A general analysis of the individuals may be interesting previously to the first session (for example, identity cards gathering the students’ interests and backgrounds – professional or academic - may be extremely useful to better adapt the session dynamics).

There are usually some student roles that may be clearly identified and diagnosed during the first or second session of the course. The facilitator has to moderate participation when needed, at the same time that creates an encouraging atmosphere for those students that may feel reluctant to communicate. At this point, it is important to note that cultural differences (related to nationalities) are also a factor to consider when designing the on-site session.

When preparing a case-based course for undergraduates, it is necessary to bear in mind that the audience is probably to be homogeneous, not differing in professional background, as it is the case for master students. Of course, there are exceptions to the rule, but the session dynamics will probably stick closer to the prepared outline. In master courses, the diversity of participants usually enriches discussions, as each student may provide different and valuable approaches to the same problem.

Supporting materials

The selection of materials to support the course is a critical factor. There are several sources where potentially suitable cases for undergraduates are available (Jennings et al., 2005), but these cases usually need to be adapted: shortened, clarified, completed or simplified.

Undergraduate cases usually need to be brief and more focused than ‘standard’ ones. The latter are typically long and very detailed, in order to provide the student with complete information and make him/her discard it when distorting the analysis. For undergraduates, to a certain extent, it is necessary to keep the problem ‘simple’ and focused, and that may mean to substantially reduce the complementary details of the situation described in a standard case.

Combining case descriptions with other pieces of information in attractive formats is very reasonable when targeting undergraduates. For example, news, advertisements, multimedia contents, excerpts of scientific papers or financial reports, patents, interviews with relevant people, etc. help to bring the case to reality, making it easier to contextualize and understand. Including comments to hot topics is also an effective way to catch the audience’s attention.

Creating a new case from scratch is a laborious process; apart from writing the class itself (defining the case issues, the target student analysis and gathering complementary data to build the case – a process that Harvard Publishing estimates that last for 4 months), it implies defining and validating the teaching on-site dynamics. This validation procedure
should be done before using the case first time, usually relying on colleagues or grade students that may give useful feedback before getting the class floor.

Course organization

An important hindrance we have found when facing the design of case-based sessions is the difficulty to balance homework with the supposed ‘lecture’ duration: case preparation usually makes the student to work for a reasonably long while before attending the course. Our global study plan is not prepared for this, so in our first experiences (before migrating the whole course to a case-based structure), we have tried to simplify cases, and organize sessions to integrate theory delivery and problem analysis with case solving (in order to reduce the workload to be done as homework).

Of course, this is not the optimal scenario to work with cases, but it can be a starting point to facilitate migration from one methodology to the other.

Assessment

The assessment methodology has to be very clear when working with cases, as it differs from the traditional modes. Assessment usually includes an evaluation on the quality of the student participation during the session. This is motivating from the point of view of class preparation, on-site active thinking, development of oral skills or social interaction. On the other hand, it can also inhibit the free flow of discussion, being affected by externalities, such as class size, driving personalities, difficulties for the facilitator to calibrate intervention times, etc.

Measuring in-class performance may be complemented (although not usually substituted) with homework case analysis and in-class formal outcomes (e.g. a brief exercise may have to be handed in by the end of the session). In any case, it is important to state clear how the grading process is going to be, and have it into account in the course dynamics.

A relevant aspect when opting for in-class assessment is to avoid relying on vague impressions of the quantity or quality of a student’s participation (UTDC, 2004). That means to define an objective guideline for evaluation needs. For example, it has to include the skills that students have to show and how these abilities can be developed during the course.

Dealing with group discussion and individual assessment at the same time may be complicated for the instructor. For this reason, students are usually asked to sit on the same place during all course sessions to facilitate identification. The instructor may then use a photomap of the classroom, which helps him to annotate the evaluations by using visual memory. It is important to note that assessment has usually to be completed just immediately after the session.

Effectiveness evaluation

Delivering case-based sessions can be considered enriching from the facilitator side, as no session is going to be exactly the same than the previous or the following one, due to the great importance that the student group has in it. Nevertheless, it is usually a costly and
controversial method, which has been questioned in many occasions (Savery, 2006). When starting with the technique, it is a good idea to think on how to measure performance or effectiveness, in order to check if we are getting the results we want from it. Surveys or personal interviews with students may be interesting to have real feedback on the students’ feelings towards the new method.

Conclusions

In this paper, we comment on some the key aspects that need to be addressed when considering delivering a case-based course to students of technical degrees. Conceiving a case-based undergrad course imposes some design decisions in: 1) the course organization, regarding work time distribution and evaluation, 2) the materials used, as specific cases, usually shorter and narrower than the standard ones are needed, and 3) the course delivery, being necessary a group analysis to adopt the right techniques to motivate the audience.

From our experience, we think that, if conveniently adapted, case-based learning may be a powerful tool to initiate undergrad students on the analysis of engineering problems. This technique may be especially useful to motivate and convey the relevance of non-technical courses in engineering, for example, those related to business and project management. Technical courses may be transformed in a similar way using PBL; nevertheless, we find that it can be risky to migrate strictly scientific or technical subjects to inquiry-based methods such as the ones commented here.

References


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Disassemble/Analyse/Assemble (DAA) activities: Learning Engineering through Artefact Interactions

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Abstract: Disassemble/Analyse/Assemble (DAA) activities involve the systematic deconstruction of an artefact, the subsequent analysis, and possible reconstruction of its components for the purpose of understanding the embodied fundamental concepts, design principles and developmental processes. These activities have been part of regular industry practice for some time; however, the systematic analysis of their benefits for learning and instruction is a relatively recent phenomenon. A number of studies have provided highly descriptive accounts of curricula outcomes of DAA activities; but relatively few have compared participants doing DAA activities to a control group doing more traditional activities. In this respect, a quasi-experiment was conducted as part of a first-year engineering laboratory, where a DAA activity was compared to a lecture method of instruction. The results showed that students who engaged in the DAA activity were more motivated and demonstrated higher frequencies of transfer than the students who had the traditional instruction.

Introduction

Engineering thinking develops largely through interactions with artefacts, the material aspects of our physical world. Engineers interact with artefacts as creators, bringing them into existence; curators, maintaining and furthering them; and controllers, extending knowledge and access of and to these artefacts. Studying the pedagogical affordances of these artefact interactions has the potential to reveal new ways in which we can nurture engineering thinking through contemporary engineering education. One notable form of artefact manipulation is observed in Disassemble/Analyze/Assemble (DAA) activities. The study described in this paper explores the relative potential of DAA activities for learning and instruction in engineering.
Ogot and Kremer (2006) introduced the term “Disassemble/Analyze/Assemble,” to identify educational activities patterned after the industry practice referred to as either reverse engineering, product teardown or product dissection. In an industrial setting these practices are used by companies to compare their products, services and practices to their competitors, identify ways to reduce cost, improve quality, and identify innovative ideas (Kutz, 2007; Otto & Wood, 2001). When used in an educational context, these activities help students understand the structural, technological and developmental principles of the artefact under investigation. Inherently a discovery-based pedagogy, DAA starts with the artefact; an instance of a typically well engineered solution. Through systemized disassembly and the subsequent analysis of components, students engage in a potentially self-directed iterative process of observation and follow-up probing. In-turn, this process helps students understand the function of the artefact's components and their interconnection with each other and the operation of the artefact. Typical discovery activities such as inventing or construction tend to be flawed by their inability to constrain students' explorations and prevent deviation from the intended focus. DAA activities attempt to overcome this challenge by starting with the expert version; an approach that has shown success at facilitating learning, transfer, and motivation (Dalrymple, 2009).

Reviews from instructors and students support claims of DAA’s successful utilization in engineering learning environments. The following learning outcomes have been ascribed to DAA: helping students identify relationships between theoretical concepts and their real-world instantiations (Brereton, Sheppard, & Leifer, 1995), providing hands-on activities to couple engineering principles with significant visual feedback (Barr, Schmidt, Krueger, & Twu, 2000; McKenna, Chen, & Simpson, 2008), encouraging the development of curiosity, proficiency and dexterity (Beaudoin & Ollis, 1995; Hess, 2002), increasing motivation and retention (Carlson, Schoch, Kalsher, & Racicot, 1997), and supporting design learning (Devendorf, Lewis, Simpson, Stone, & Regli, 2007; Ogot, Okudan, Simpson, & Lamancusa, 2008; Wood, Jensen, Bezdek, & Otto, 2001). Recent explorations conducted by the authors into the pedagogical viability of DAA, have experimentally confirmed DAA's ability to elicit motivation over more traditional forms of instructions (i.e. step-by-step lab instructions) and identified the additional benefit of promoting transfer to novel design problems (Dalrymple, Sears, & Evangelou, 2011). A follow-up study, which is described in this publication, extends on the authors' initial findings by further isolating the factors in DAA that are instrumental to students’ learning and motivation. In this new study, DAA is compared to to a lecture method of instruction. Both instructional methods are designed to help students learn the same content knowledge; an improved comparability from the previous study. This allows for evaluations on multiple dimensions of learning (e.g., factual recall of part-function relationships and multiple measures requiring redesign or knowledge transfer) and motivation so that a more complete picture of the effects of DAA can be established.

**Research Questions / Hypotheses**

In the first U.S. edition of Donald Bligh’s “What's the Use of Lectures?”(2000), a lecture is defined as “a period of more or less continuous exposition by a teacher.” Bligh also provides the outcomes of numerous experimental comparisons to substantiate the claim.
that lectures are as effective as other methods of instruction for transmitting information. He also goes on to validate in the same manner that lectures are not as effective as discussion methods for the promotion of thought and relatively ineffective for inspiring interest in a subject. Thought as described by Bligh can be likened to the cognition or deeper understanding required to enable transfer to novel problems, and interest in a subject matter likened to motivation. Hence it is within reason to expect the outcomes achieved in the first study to persist. It was hypothesized that on measures of motivation, the DAA activity will be rated higher than the lecture; on measures of recall, the DAA activity and lecture will result in equivalent performance; and on measures of deeper understanding like the application of knowledge to redesign or defect diagnosis tasks, DAA will result in higher frequencies of transfer.

Method

A laboratory was designed to introduce first-year engineering students to the principles of design for the environment (DfE) through the study of a Fujifilm single-use camera. DfE refers to the systematic consideration of design performances with respect to environmental, health, and safety objectives over the full product life cycle. Fujifilm applies these principles in the design and development of its line of single-use cameras. The single-use cameras are produced in an inverse manufacturing facility where 99% of used cameras are either remanufactured or recycled to produce new generations of the product. Both a lecture and a DAA activity were utilized to help students learn about the design of the camera. With the DAA activity, students disassembled the camera and analyzed its components to discover their function and interconnectedness, while the lecture presented similar content with the use of a multimedia PowerPoint presentation. To measure and compare the learning outcomes from each instructional method, yet ensure all students had an equivalent learning experience, the lab was completed in one of two sequences: 162 students did the DAA task before the lecture (Sequence 1 – DAA First) and 163 students had the lecture before the DAA task (Sequence 2 – Lecture First). Assessment activities preceded and followed each instructional method to measure the extent to which the DAA activity and the lecture facilitated learning and transfer of knowledge about the function and interconnectedness of the components used in the camera's design to solve novel problems. Table 1 shows the design of the study and the sequence of tasks in the lab. The details of this design are described in the following sections.
Table 1 - Study Design / Task Sequencing

<table>
<thead>
<tr>
<th>Duration</th>
<th>Task #</th>
<th>Sequence 1 (DAA First)</th>
<th>Sequence 2 (Lecture First)</th>
<th>Task Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 min</td>
<td>-</td>
<td>Introduction</td>
<td></td>
<td>Class</td>
</tr>
<tr>
<td>10 min</td>
<td>1</td>
<td>Pretest - Match Components to Functions</td>
<td></td>
<td>Individual</td>
</tr>
<tr>
<td>30 min</td>
<td>2</td>
<td>DAA Activity</td>
<td>Lecture</td>
<td>Team / Class</td>
</tr>
<tr>
<td>20 min</td>
<td>3</td>
<td>Posttest 1 - Variant Design, System Decomposition &amp; Camera Doctor</td>
<td></td>
<td>Individual</td>
</tr>
<tr>
<td>30 min</td>
<td>4</td>
<td>Lecture</td>
<td>DAA Activity</td>
<td>Class / Team</td>
</tr>
<tr>
<td>5 min</td>
<td>5</td>
<td>Posttest 2 - Unwanted Features</td>
<td></td>
<td>Individual</td>
</tr>
<tr>
<td>7 min</td>
<td>-</td>
<td>Post Lab Survey</td>
<td></td>
<td>Individual</td>
</tr>
</tbody>
</table>

Introduction: The lab began with an 8-minute PowerPoint presentation delivered by the lead researcher. In the presentation, DfE was described and demonstrated in the design and development of Fujifilm’s line of QuickSnap single-use cameras. Students were also given an overview of the lab tasks to follow and procedural instructions for accessing the online assessments.

Task 1 (Pretest): The first task was the same in both sequences and it served as the pretest. It provided a measure of student’s prior knowledge with respect to the design of the single-use camera that will be studied in the lab. Using an instrument administered online, students were asked to match the components of the camera to their functions. Each of the eight questions contained a different function description, and pictures of 8 components from the Fujifilm QuickSnap Outdoor 1000 single-use camera. Students were instructed to select the component that fulfilled the described function.

Task 2: The second task was either the DAA activity (Sequence 1) or the lecture (Sequence 2). For the DAA activity, students were given an instruction sheet that introduced the concept of reverse engineering and its application in industry as a tool used by companies to compare their services and practices to competitors. Also included was a description of a fictitious company interested in developing a line of single-use cameras that wanted to learn more about the design of the Fujifilm single-use camera. Students were asked to assist in this venture by working in teams to systematically disassemble a Fujifilm QuickSnap Outdoor 1000 camera. They were also asked to use any representation of their choice to record the camera components along with a description of how each component functions to make the camera work. With the exception of a few hints to help start the disassembly process, student teams approached this task in their own way, probing their observations to the extent they deemed necessary to understand the camera’s design.

In the lecture the design of the Fujifilm QuickSnap Outdoor 1000 camera was presented using a multimedia PowerPoint presentation. The presentation began with a brief history of one-time use cameras and the development process used by Fujifilm. Following this, all components of the camera, starting with the packaging were identified and their functions described. The components were presented in the order one may encounter the parts if disassembling the camera.
Task 3 (Posttest 1): The third task was the same in both sequences, and it served as the first posttest. Using an instrument administered online, students were asked to respond to three types of questions (i.e., variant design, system decomposition and camera doctor). The three question types relate to common tasks performed in the engineering design process. All questions were designed to engage the knowledge students were expected to have gained about the functions and interconnectedness of the camera components from the previous task (DAA or lecture). A description of the three question types and their relation to engineering design follows.

- System decomposition refers to the process of dividing a system into smaller parts or subsystems for the purpose of reducing complexity. It occurs in the problem definition phase of the design process to facilitate a better understanding of the problem to be solved. A system can be decomposed according to function, user actions or key customer needs (Ulrich & Eppinger, 2004). For the system decomposition component a different user or camera action (i.e., aim, shoot, wind, and protect film) was described in each of the four questions. Also included in each question were the pictures of eighteen Fujifilm QuickSnap Outdoor 1000 camera components. Students were required to identify all the components that function to allow each described action to occur.

- Troubleshooting is the common engineering task that students were asked to perform with the Camera Doctor questions. It is a form of problem solving that is applied to the repair of failed products or processes, and is very prevalent in the testing phase of the design process. Troubleshooting requires an integrated understanding of how the system being troubleshot works (Jonassen, 2000). For the camera doctor component, examples of photographs taken with cameras with different defects were presented in each of the four questions. Also included in each question were the pictures of eighteen Fujifilm QuickSnap Outdoor 1000 camera components. Students were required to diagnose the defect that would have lead to the poor photograph by choosing the malfunctioned user or camera action (aim, shoot, wind, or protect film), selecting the components that may be defective from the eighteen components presented, and describing what may have happened within the camera.

- Variant design is one classification of engineering design. It involves varying the parameters of certain aspects of a product to develop a new and more robust design (Otto & Wood, 2001). Variant design techniques are used to create scaled product variations for a product line. For the variant design component two scenarios were presented, each describing a need for new camera functionality (i.e., three different shutter speeds and a viewfinder that can be used to see any object blocking the lens). Students were asked to describe how the original design of the camera could be modified to achieve the new functionality.

Task 4: The fourth task was either the lecture (Sequence 1) or the DAA activity (Sequence 2); a reversal of task 2 such that all participants would experience both instructional methods.
**Task 5 (Posttest 2):** The fifth task was the same in both sequences and it served as the second posttest. Using an instrument administered online, students were presented with images of eighteen Fujifilm QuickSnap Outdoor 1000 camera components and asked to select from this group all the components that function to prevent the superimposing of images (i.e., multiple pictures being captured on the same film frame). This task, like task 3, was designed to engage the knowledge students were expected to have gained about the functions and interconnectedness of the camera components. Following both instructional tasks, this assessment allowed the effect of different task sequences to be determined.

**Post Lab Survey:** Following task 5, students completed a post lab survey administered online. Students responded to questions about their background and perception of both instructional tasks. Using the seven-point likert scales used in the first study, students rated both the DAA and lecture on: 1) perceived sense of learning, 2) enjoyment derived from engaging in the activity, and 3) helpfulness in preparing them to respond to the variant design question given in task 5. The three aforementioned elements were used to measure the motivation elicited from each instructional task. Students also rated their prior experience disassembling objects using a seven-point scale that ranged from (1) no experience to (7) extensive experience.

**Results**

With respect to motivation, the results were consistent with previous findings from the first study (Dalrymple et al., 2011). Using paired samples t-test on each element of the motivation measure, the mean ratings for the DAA task were found to be significantly higher than the mean ratings for the lecture. On students’ perceived sense of learning which ranged from nothing (1) to a lot (7), the mean rating for the DAA task was 5.30 ± 1.24 (M ± SD) and for the lecture task it was 4.84 ± 1.26, t (324) = 7.580, p < .001. On enjoyment derived from engaging in the activity which ranged from strongly disliked (1) to strongly liked (7), the mean rating for the DAA task was 5.87 ± 1.18 and for the lecture it was 5.23 ± 1.31, t (324) = 10.641, p < .001. On helpfulness in preparing students to respond to the variant design question in task 5 which ranged from not helpful (1) to very helpful (7), the mean rating for the DAA task was 5.15 ± 1.22 and for the lecture it was 4.81 ± 1.25, t (324) = 5.263, p < .001.

Regarding learning, the three posttest questions (i.e., system decomposition, camera doctor, and variant design) that were used to characterize the potential differences between lecture and DAA for learning and transfer, each varied in context relative to the instructional/initial learning tasks. The system decomposition questions most closely related to the context of initial learning and tested for students’ ability to recall the associations between camera parts and their function. The camera doctor questions asked students to diagnose defects in a camera based on the analysis of photographs. These questions retained some aspects of the component-function association and inadvertently tested for recall, however they deviated into the realm of novel problem solving, asking students to diagnose the presented symptoms and generate hypotheses about the source of the malfunction (Jonassen, 2000). The variant design questions deviated most from the context of initial learning, testing for the greatest distance of transfer. These questions
required students to modify the current camera design to achieve new functionality (e.g.,
three different shutter speeds). Design problems are the most complex and ill-structured
kinds of problems (Jonassen, 2000). The results showed that the DAA activity had
advantages over lecture in terms of recall and transfer. Students who did the DAA activity
scored significantly higher than those who had the lecture on the system decomposition
questions, *t* (315) equal variances not assumed = 3.09, *p* = 0.002 (M ± SD = 3.19 ± 0.31 and
3.09 ± 0.27 for DAA First and Lecture First respectively). On the variant design questions,
62% of DAA First students vs. 30% of Lecture First students, noticed and adapted the
appropriate mechanism in the Fujifilm camera to achieve new functionality, χ² (1, N =
325) = 46.557, *p* < .001. On the camera doctor questions, students that did the DAA activity
were able to generate significantly more plausible hypotheses about the reason for the
camera malfunction, *t* (323) = 2.026, *p* = .044 (M ± SD = 1.26 ± 0.90 and 1.06 ± 0.87 for
DAA First and Lecture First respectively).

**Significance of Findings and Future research Plans**

The results of the previously described experiments raise a number of points with respect
to learning and transfer. Firstly, it is important to note that the DAA activity lead to greater
transfer as observed in the initial study, without the added cost of additional instruction or
basic understanding. In fact, this study showed that DAA resulted in higher scores on
system decomposition questions, which measured factual recall. Secondly, it is impressive
that students with one exposure to one camera were able to notice and adapt its features
to develop a new design and diagnose defects in a camera after viewing flawed
photographs. In other literature on transfer, it often takes multiple exposures for students
to notice a key feature (e.g., Gick and Holyoak, 1983). In studies of Innovation activity,
multiple contrasting cases were provided to help students be able to adapt their
knowledge (e.g. Sears, 2006). In this sense, being able to adapt knowledge after one
exposure is impressive and reveals a potential key advantage of the DAA process (iteration
of observation and follow-up probing). The third point reveals a challenge: both studies
involved a camera, a tangible and predominantly mechanical device, as the artefact under
investigation; would the observed benefits remain true for other types of engineering
artefacts? The DAA framework has already begun to show promise at cultivating student's
adaptive expertise in engineering, i.e., ability to apply knowledge effectively to novel
problems. These early findings push for further examination to test the generalizability of
the claims. New types of engineering artefacts, beyond those that are predominantly
mechanical and/or, tangible, need to be assessed.

**References**

through an integrated reverse engineering and design graphics project. *Journal of


Acknowledgements

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The transferability of the PSVT:R and the MCT for Measuring and Predicting Student 3D CAD Modelling Abilities

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Abstract: Engineering graphics is a fundamental skill required for students to be successful engineers; in the past, a year-long, two-course sequence was devoted to teaching the skills of spatial visualization and hand sketching. Today most engineering programs allot a single semester to teaching both the hand sketching component of engineering graphics and the application of a 3D solid modeling program. Therefore, it is critical for faculty to be efficient in their delivery of course material while still ensuring that students are learning and understanding the key concepts. Two of the better known assessment tools in engineering graphics research are: the PSVT:R, the Purdue Spatial Visualization Test: Rotations and the MCT, the Mental Cutting Test. While both of these tests have been used to predict a student’s success with spatial visualization and hand sketching neither have been used to predict a student’s success with the development of 3D solid models. This paper focuses on the transferability of the PSVT:R and the MCT in predicting and measuring a student’s 3D modeling abilities.

Context and Purpose Statement

In 2000, ABET, (originally named Accreditation Board for Engineering Technology), issued its revised objectives for the accreditation of undergraduate engineering programs. These revised objectives required a fundamental shift from a numerical list of minimums (i.e. number of hours teaching, number of PhD faculty in department, etc.) to an open list of objectives that each institution could then tailor to their specific programs. Institutions are also now required to provide assessments that “identify, collect, and prepare data to evaluate the achievement of program outcomes and program educational outcomes” (p. 2) (ABET, 2009). Program education objectives are the overarching statements that define the career and professional achievements expected of the program graduates, and program objectives are the more narrowly defined descriptions of what students are expected to know and be able to do by graduation – the skills, knowledge, and behaviors acquired (ABET, 2009). Institutions are to formatively evaluate the data and evidence generated by the assessments to continuously improve their programs.

The four ABET 2000 outcomes that directly relate to the freshman graphical communication class are:

a. an ability to apply knowledge of mathematics, science, and engineering  
b. an ability to identify, formulate, and solve engineering problems  
c. an ability to communicate effectively
d. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Demonstrating that these two assessment instruments, the PSVT:R and the MCT are also valid and reliable for measuring 3D modelling skills can significantly contribute to the ABET required assessment of program goals. The gathered results may be used to both formatively assess the learning gains of individual students as well as to summatively assess and compare the performance across all sections of the course.

The purpose of this research project is to demonstrate that the PSVT:R and the MCT can measure and predict student understanding of the concepts that comprise an introductory graphical communication course – specifically 3D modeling. It is expected that students with weaker understanding of these concepts will not score as well on these two assessments as those with a stronger understanding. Lower performing students are at a higher risk of becoming discouraged with engineering and subsequently withdrawing from or failing out of the program. Higher performing students are at risk of becoming bored with and disengaging from engineering. Implementing these two assessments could aid educators and administrators in placing students in the appropriate course per their skill level by accurately identifying the lower, the middle, and the higher performing students. The two instruments may also be used as a pre and post-assessment for the middle and lower performing students to demonstrate their learning gains. The results of the assessments may also be used to develop new and refine existing lesson plans to address the consistently identified student misconceptions.

**Theoretical Framework**

Engineering graphics teaches a fundamental skill, the language of engineering, required for students to be successful engineers (Orth, 1941; Rising, 1948; Svensen, 1948). In the past, engineering graphics was taught as a one year, two course sequence. This allowed faculty enough time to identify and correct theoretical and practical misconceptions and afforded students enough time to develop their weak spatial abilities. As the engineering curriculum changed, most colleges and universities have compressed the two course sequence into one course or have even further reduced it to a module embedded within another course. Aggravating this cognitive overload is the addition of 3D computer graphics and modeling. Spatial abilities as applied in graphical communication are not easily learned and many students require significant time and guidance to develop these skills properly.

3-D spatial abilities are not a singular construct, but rather a collection of specific skills – spatial visualization and spatial orientation (Contreras, Rubio, Pena, Colom, & Santacreu, 2007; Olkun, 2003; Quaiser-Pohl & Lehmann, 2002; Smith, 1964; S. A. Sorby, 1999; Strong & Smith, 2002; Voyer, Rodgers, & McCormick, 2004). Spatial ability is the over-arching term encompassing: mental rotation, mental transformation, spatial orientation, and spatial visualization. Figure 1 shows the structure of these interdependent concepts. Spatial ability involves mentally moving an object. It is the ability to manipulate an object in an imaginary 3-D space and create a representation of that object from a new viewpoint or perspective, a combination of spatial visualization and spatial orientation.
Figure 1 - Spatial Visualization Classification Structure (McGee 1979)

Spatial visualization is comprised of two skills – Mental Rotation and Mental Transformation. Mental rotation is the skill of transforming the entire object by turning it in space. Mental transformation is the skill of altering only a portion of the object. Spatial orientation is the ability to mentally move your viewpoint while the object remains fixed in space. Strong and Smith (2002), offer two examples of spatial orientation: a diver even though she may be turning and twisting, knows exactly where the water is; and a stunt pilot knowing where the ground is during his maneuvers.

The ability to visualize objects and situations in one's mind, and to manipulate those images, is a cognitive skill vital to many career fields, especially those requiring work with graphical images. By one estimate, there are at least 84 different careers for which spatial skills play an important role (Smith, 1964). Spatial ability is an essential skill for Science, Technology, Engineering and Mathematics (STEM) fields. Spatial abilities have been widely studied and are known to be fundamental to higher-level thinking, reasoning and creative processes (Bishop, 1978; T. Branoff, 2009; J. T. Demel, Frank M. Croft, Frederick D. Meyers, 2002; J. T. Demel, Frederick Meyers, & Harper, 2004; Gorska & Sorby, 2008; A. H. Hamlin, N Veurink, & S. Sorby, 2008; A. H. Hamlin, N. Boersma, & S. Sorby, 2006; Harris, 2007; Smith, 1964; S. A. Sorby, 1999, 2001, 2003, 2007, 2009; S. A. Sorby, & M. F. Young, 1998). For technical professions, such as engineering, robotics, and GIS (Geographic Information Systems), operate laparoscopic equipment (Eyal & Tendick, 2001), and to interact efficiently with database management (Norman, 1994), spatial visualization skills and mental rotation abilities are especially important (A. H. Hamlin, N. Boersma, & S. Sorby, 2006; Yue, 2006). Ferguson (1992) believes that several well-known engineering failures: the Challenger explosion, the Columbia disaster, the Hubble space telescope, and the USS Vincennes Aegis system, have occurred due to the removal of visual, tactic, and sensory applications from the current engineering curriculum.

Students struggle with the transition from 2D to 3D and back to 2D, only with time and repeated structured guidance are students able to properly develop these skills (J. T. Demel, et al., 2004). Given the limited course time now available, engineering graphics
faculty must be efficient in their delivery of the course material to ensure that students are learning and understanding the key concepts to engineering graphics. A standardized engineering graphics concept inventory would allow for faculty to identify key areas of student misconceptions.

Traditionally students’ spatial abilities were improved as a by-product of the engineering graphics curriculum and not due to any formally addressed outcomes. Ferguson (1992) claims that the engineering education of today has diverged too much from its artistic, visual beginnings, and that the curriculum relies too heavily on analytical methods and not enough on tactile and visual perception. With the integration of the ABET 2000 criterion a-k there has been a shift in engineering education to outcomes based assessment (Barr, 2003, 2004, 2005). One of the frequently cited educational outcomes of engineering design graphics is the development of student’s 3-D spatial visualization abilities. During the last decade there have been some changes in the contents of the Engineering Graphics discipline, but barring some exceptions, spatial abilities are still considered as a secondary goal that simply is achieved through the learning of other concepts (Contreras, et al., 2007).

Since the release of ABET EC 2000 – specifically criterion 3a-k, engineering educators have searched for appropriate methods to provide supporting data that they are meeting the requirements for student learning and outcomes. Validated instruments, implemented as a pre and post-test assessment, would provide much of the data required to show an engineering graphics course is meeting established ABET student outcomes of a, g, and k.

The instruments are to be used to measure and establish a baseline of student 3D modeling ability in engineering graphics. These abilities are a fundamental skill required of all engineering students. Students who have these skills are able to decompose a 3-dimensional (isometric) object into the proper 2-dimensional (orthographic) views and be able to construct the appropriate 3-dimensional object from multiple 2-dimensional views. Students who have very weak to no visualization skills are not able to properly complete these tasks.

Methods

Sample

A purposeful sampling strategy (Creswell, 2009) will be employed, using the course sections of teachers who taught with a high level of CATIA, a 3D solid modeling software. This research is to measure the predictive abilities of the PSVT:R and the MCT in relation to students’ 3D modeling skills. For the purposes of the study discussed in this paper, a sample size to be selected will provide for a range of students with similar and disparate 3D skills.

In late August 2011, the PSVT:R and the MCT will be administered to 300 students in 15 sections of EGR 120, graphical communications, in one setting, a private undergraduate institution in the southeast. The demographic data for the sample test will be provided for the presentation.
The Assessment Instruments

Purdue Spatial Visualization Test: Rotations

The PSVT:R was developed by Guay (R. Guay, 1977) at Purdue University. In this timed 30 item test participants are asked to visualize the direction and rotation of the provided sample model, next they are to visualize what the second object would appear as if it were rotated the same as the sample, and then they are to select the correct image from the five options provided. A sample question from the PSVT:R is provided in Figure 2.

![Figure 2 - Sample PSVT:R Question](image)

Mental Cutting Test, MCT

Developed in 1939 as a college examination, the CEEB Special Aptitude Test in Spatial Relations has been used for many years to determine spatial ability. The MCT is a timed 25 problem test divided into two categories: pattern recognition and dimension specification. For the former type of problem only the pattern of the section needs to be identified to determine the correct answer, for the latter both the pattern and the correct dimensions need to be identified. As sample question from the MCT is provided in Figure 3.

![Figure 3 - Sample MCT Question](image)

The reported reliability of the PSVT:R, KR-20 was .87, .89, and .92 for university students (Bodner & Guay, 1997; R. B. Guay, 1980; S. A. Sorby & Baartmans, 1996) and the reported reliability of the MCT, Chronbach’s α, of the MCT was .87 and .92 for undergraduate chemistry and engineering students (T. J. Branoff, 2000; Caissie, Vigneau, & Bors, 2009, p. 1). While these tests have a long history of reported reliability they have only been implemented to predict hand sketching not 3D modeling abilities.
Data Collection

The PSVT:R and the MCT will be implemented to 300 students in 15 sections of EGR 120, in August 2011. The instruments will be completed during the regularly schedule class time. Each teacher will be briefed on the two tests and their administration. The tests will be paper-based and timed. The teachers will be provided with written directions, describing the procedures for administering the PSVT:R and MCT. The tests will be administered prior to any classroom instruction on 3D solid modeling.

Of the 300 hundred students to be tested, two from section will be interviewed as a means of critically examining how students constructed their 3D models. One higher performing and lower performing student from section, the aggregate scores from both instruments will be used as the selection criterion. Participants will be asked to review their answers on the two tests as well as describe their modeling strategies of several 3D solid models.

Data Analysis

Data Analysis will involve two phases. The first phase will involve a detailed item analysis of both instruments, to determine the validity. Statics to be reported for all items on both tests are: item discrimination, item difficulty, and item total score correlation. Overall instrument validity for the PSVT and MCT will also be determined. This information will be provided for the presentation.

The second phase will involve a content analysis of the students' responses in the interviews. This data analysis process will be inductive (Krippendorf, 2003). This information will not be provided for the presentation.

Findings/Conclusions/Recommendations

As this paper is documenting research in progress, findings, conclusions, and recommendations will not be available until September 2011 and will be provided for the presentation.

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Branoff, T. (2009). *Large course redesign: Revising an Introductory engineering graphics course to move from face-to-face to hybrid instruction*. Paper presented at the ASEE Annual Conference and Exposition, Austin, TX.


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Novel Hybrid Training Tool Based on Experimental Projects in Electronic Engineering Education.

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Abstract: This paper describes a novel hybrid electric machine and power electronic training tool (EM&PETT) for enhancing the uses of experimental laboratories for education in electronic engineering. The EM&PETT is developed to help increasing electronic engineering students' motivation for studying in areas of power electronic converters and electric machine control. The scheme proposed is to create a control system divided in open modular blocks, all of these hardware and software blocks are accessible, without “black” boxes. The students can redesign any of these blocks and introduce them into the original system, which are then tested through the use of virtual and real tools. The possibility of introducing parameters and variables that are difficult to manage in commercial equipment promotes an increase in academic proficiency. The proposed training tool is integrated in a hybrid virtual-experimental laboratory platform, within which students can share on-line theoretical information and practical experiences.

Introduction

Feisel and Rosa (2005) analyze the responsibility of the experimental laboratory know-how as a fundamental part of engineering education. The significance of these educational environments is unquestionable and in recent years different publications, (Peterson and Feisel, 2002; Lazar and Carari, 2008; Jara, Candelas, et al., 2009; Shih and Hwang, 2010), have proposed innovative solutions to enhance experimental training in virtual and remote laboratories.

Over the years there has been an increase in problems related with the cost of power electronic experimental laboratories, the high ratio of students to professor and safety issues associated with the high voltages and currents present in electric energy converters. For example, Shirsavar, Potter, and Ridge (2006) propose a low cost and a low power laboratory application for electric machine control. But in general, these problems
have been leading the practical activities to solutions based in simulation software, (Chung, Harmon, and Baker, 2001; Macías, Cázares, and Ramos, 2001; Shih and Hwang, 2010).

The extensive use of simulation practices without real experimentation, in our opinion, is producing a loss of technical skills and motivation by the students in experimental practices in power electronic and electric machine control and a potential loss of attractiveness in these disciplines, (Undeland and Mohan, 2002). The idea is to promote these areas of engineering through, in many cases, quasi industrial application projects, (Max, Thiringer, Undeland and Kalsson, 2009).

The methodology presented here introduces a novel learning structure for developing real projects in a hybrid virtual-experimental laboratory that utilizes simulation software, the hands-on laboratory and the computer as a transformation tool. The proposal based on the training tools attempts to improve the experimental skills allowing, at the same time, the work of an elevated number of students in a shared environment that approximates an industrial reality and providing, on the other hand, motivation for developing new applications into the proposed scenarios.

The most outstanding technical characteristic of these hybrid electric machine and power electronic training tools (EM&PETT) is their flexibility. The aim was to create an environment within the power electronics converters and electric machine control areas that allows the introduction of HW and SW designs made by the students. There is full access to all components of the system, there are no “black” boxes for students, they work in a block but they have access to whole HW and SW modules.

Figure 1 shows the number of final projects in Industrial Electronic degree from 2004 to 2010 and, in the same years, the number of students in Industrial Electronic degree at Technical Engineering School of Bilbao, in the Basque Country University. It can be observed the high demand from students for careers in the fields of electronics and the growing demand for final projects.

![Figure 1: Final Projects and student numbers evolution in Industrial Electronic Degree](image)

The next sections present the power electronic training tool, its physical structures, its practical and theoretical potential and the final conclusions.
Power electronic training tool architecture

The proposed training tool architectures consist of a power electronic system, equipment needed by the students in their HW and SW designs, a methodology for developing these designs and a shared environment for controlling and analyzing the system on-line. Figure 2 shows an “Open” tool for working with PMDCM (Permanent Magnet DC Motor) and the remote control environment created specifically for this tool.

In our proposal, Freescale’s DSC 56000E family has been selected as basis of these training tools, because it has twin integrated peripheral blocks that allow, for example, the simultaneous control of two complex electronic converters with the same development board. Besides the software for the most technical applications in undergraduate level can be done with CodeWarrior Development Software Tools free software, it has unlimited assembler, C compiler limited in C object code size to 64KB, Quick Start tool and the free communication software FreeMaster, which allows the user, student or professor, to create his or her own DSC software control application in the modular converter and its interface page control through the use of HTML, Visual Basic Script and Java Script programming, Figure 2.

Figure 3 shows two “Rack” training tools, as shown in the photograph they are mounted on an industrial rack and designed to work with high voltages and currents. This equipment, though fitted with industry safety standards are structured so that students can integrate their designs, always under the supervision of laboratory staff. Unlike the Open tools that could be completely changed if a project requires it, the Rack tools support only partial modifications of the blocks that compose them, the difficulty of their designs is beyond the scope of a graduate student. The use of these tools has been extended to masters and doctoral students.

The system promotes that each student has carefully studied their proposed solution prior to its presentation for implementation. The students can compare the evolution of their design solutions.
Other learning uses

The training tools proposed in this paper present many possibilities as a real time audiovisual monitoring control tool.

In the classroom via the class or personal computer the access to the hardware project can be made through the remote control and observed by the audio-visual equipment. This capability allows the professor to design the class lecture of the day and demonstrate to the students in real time specific material and observe in any level of detail its application in the modular real system. Figure 2 shows a computer screen in which the remote control of the system can be observed and controlled via two cameras. With one camera, top right, the modular converter or any of the introduced designs in the system can be observed and with the other camera, bottom right, the operation of the electric machine can be seen and heard.

The possibility of integrating in the same platform the hardware and software control and visualization, the theoretical knowledge related with these modular blocks and the relationship between the hardware design and the commercial components integrated in it, Fig 2, the opportunity of measuring any variable involved in the project and finally the capability of utilization from any place and any time make this learning experimental methodology very realistic for engineering education.

And lastly, the low cost of discrete electronic components permits considering these training tools as a possible experimental learning tool for distance education.
Results

In recent years these tools have been applied in the development of several final projects and other experimental projects in different levels and subjects through the degree course of Industrial Electronics Engineering, such as Analog Techniques, Automatic Control and Power Electronics. Figure 4 shows the average mark of final projects developed by the students with the EM&PETT training tools against the average score of this type of activity, and the level of student satisfaction involving a hardware design project for the measurement and analog processing of currents in the phases of an electrical machine, proposed for the subject Analog Techniques in the third semester of the degree during the academic years 2007/2008, 2008/2009 and 2009/2010.

![Figure 4: Average scores of the Final Projects and results of the satisfaction surveys with Analog Techniques projects](image)

The satisfaction survey of Figure 4 reflects the opinions of students about the training tools benefits. Satisfaction with the tasks, individual work dedicated and their perceptions about the teamwork are grouped under the heading of developed activities. The section on satisfaction with the evaluation has sought the perception on self-assessment and peer assessment, and the third part about learning perception reflects the overall impression of learning.

Conclusions

The proposed learning tools achieve the four objectives that have been the aim of this project: firstly, that the students realize the design and integration of their own hardware and software designs that meet the appropriate study level and that they obtain the objectives and competencies set out in a specific subject, secondly, to create a scenario that permits the student to integrate his or her design in a modular system in the power electronic and electric machine control field, thirdly, the use of remote control for the analysis of the behavior of the integrated student designs, and lastly, the development of a shared work platform for the theoretical and practical execution of each task.
Future

The future possibilities of EM&PETT will only continue to increase, into areas such as solar photovoltaic converters. For example, the tool shown in figure 2 is intended to be autonomous from the electrical grid, being powered by solar energy.

Also planned is the extension of the application into other industrial engineering degrees as Mechanical Engineering, in subjects such as vibration in rotative machines and fatigue in shafts.

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Abstract: Ultimately, education reform probably has to be judged in economic terms in order for significant financial resources to be applied. Yet there seems to have been relatively little discussion of economic factors in engineering education research. This paper outlines an approach for discussing the economic factors in engineering education that might provide valuable insights for researchers. While cost factors are reasonably easy to identify and some can be quantified, the benefits of education are much harder to define, let alone measure. Research studies provide evidence that there is little relationship between academic and on-the-job performance by engineers, and, as yet, there are no well accepted measures of education and learning quality. This paper argues that the investment in training, professional development, and productivity opportunity costs made by an enterprise in the early years of an engineer's career could provide a proxy measure for the effectiveness of engineering education.

Economic aspects in engineering education

This paper seeks to raise some fundamental questions that seem relevant for engineering educators. What are the costs and benefits of engineering education? Behind this question lie others. For example, why does it take four or five years of university studies and another two, three or even four years of experiential learning after that for young engineers to be considered to be competent professionals? While engineering education researchers and practitioners have been advocating reform for decades, it is curious that questions on the economics seem to have been absent from that discourse.

Most engineers, whether they work in commerce, government, the military or academia, work with the daily reality of economics, if only in the form of resource constraints imposed by others and in their private lives with financial matters. Research by the author and his students on engineering practice in the commercial sphere has revealed a pervasive drive for cost-effectiveness in the daily work of engineers (Crossley, 2011; Domal, 2010; Han, 2008; Mehravari, 2007; Trevelyan, 2007, 2010; Trevelyan & Tilli, 2008). Other studies have provided similar findings (e.g. Faulkner, 2007; Kilduff, Funk, & Mehr, 1997; Korte, Sheppard, & Jordan, 2008; Kunda, 1992; Lagesen & Sorensen, 2009; Perlow, 1999). Practically all the engineers portrayed in research studies described how they were seeking to increase financial benefits for their clients or employers (either
directly reducing costs or indirectly through performance improvements), or were working within prescribed budgets or just winning contracts.

While economy pervades engineering practice and economic constraints shape the daily realities of engineering education, it is intriguing that discussions on engineering education research seem to be silent on this issue. This is, perhaps, a reflection of recent engineering education discourse that seems to have avoided a discussion on economics. A companion paper in this conference argues that the value of engineering practice, particularly the economic value, is one of several aspects of engineering practice absent from curricula <reference to be provided>. The only mention found in a detailed study of five major engineering education texts was a single brief remark attributed to Wellington (1887).

This seems all the more surprising given the large changes that have taken place in engineering education, not so much in terms of curriculum, but certainly in resourcing. In the 1960s, during this author’s engineering studies, there were just 8 students for each faculty member, and 70-80% of the faculty had significant industrial practice experience. Today in the same institution, there are 30-50 students for each faculty member and less than 10% have substantial industry experience. (Taking casual teaching assistants into account, the official student-teacher ratio is significantly less, about 22 and 28 students per teacher.) The majority of this author’s peers gained their professional credentials under the guidance of state-owned engineering enterprises that invested significant resources in educating novice engineers. The few state-owned enterprises still operating today now outsource their engineering work to private firms where, mostly, there is minimal formal guidance for engineering novices.

This paper reviews some recent contributions on the economics of engineering education and higher education in general. A discussion on the costs and benefits of education soon runs into the difficulty that, so far, there is no widely supported method to evaluate the quality of learning. While teaching inputs can, to some extent, be quantified in terms of time and direct costs, the resulting value in terms of student learning is difficult to assess. For example, several studies have suggested that the workplace effectiveness of young engineers is unrelated to their academic performance (e.g. Dahlgren, Hult, Dahlgren, Segerstad, & Johansson, 2006; Lee, 1986, 1994; Newport & Elms, 1997). The length of time or investment required for fresh graduates to become competent engineers could be useful proxy measures related to the quality of their education. In Australia, research on novice engineers in the early years of their careers has revealed that many rely on graduate development programmes run by larger companies to make the transition from graduate to competent professional. In this study, novice engineers reported that practically everything they needed to know to accomplish their work had been learned in the workplace (Trevelyan & Tili, 2008). Many smaller companies are reluctant to employ graduates because they lack the capacity to provide the intensive workplace education needed by graduates. Studies by Bailey and Barley have shown that young graduate engineers require up to an hour of one-on-one guidance daily (2010) yet they only studied explicit learning interactions, not the informal and experiential workplace learning that also takes place.
Arguing from a hypothetical viewpoint, let us suppose that novice engineers graduating from institution A are widely regarded as being fully competent professionals, equivalent to leading professionals with many years of experience, and needing no investment in workplace training. Let us also suppose that novice engineers graduating from institution B are known to be (initially) one third as productive as professionals with many years of experience, and they require 1 hour of daily guidance to develop their professional competence over four years. Then, we could estimate the investment needed to convert 'B' graduate novices to the level of 'A' graduates.

In reality, no education program could achieve the hypothetical result of 'A' above, if only because novice engineers (like any other people) need to learn the context of their work in a specific enterprise to be productive. However, we could argue about the effectiveness of education in terms of the time needed to acquire sufficient contextual learning. The time will also influence the enterprise investment required to achieve this level of competence.

Recent engineering education research has provided some interesting insights into some economic factors. Matusovich, Streveler and Miller (2010) in a longitudinal study of engineering student motivation provided a qualitative analysis of student perceptions of benefits and costs. It is clear from their research that a majority of engineering students valued engineering in terms of attainment in problem solving, intrinsic interest, and future earning capacity. Student choices to study engineering were significantly influenced by perceived costs: "For example, the costs of being an engineering student might include heavy course loads or the emotional and psychological toll associated with the financial burden of paying for engineering courses." (p297) Anticipated career costs also played a part, with some anticipating having to work long hours in remote locations and having less time to pursue other interests.

Labour market economics also can tell us that salary levels reflect the marginal product of employees. Education influences the marginal product and hence the earning capacity of an individual, represented in terms of both personal earnings and productive capacity for the enterprise. These benefits are well known, explaining why families are willing to invest in their children's education and why enterprises are willing to contribute to education through taxation and other means.

Other contributors seem to skirt around these issues, mostly in silence. For example, in an extensive review of three decades of change in higher education, including engineering education, Bowden (2009) has not once referred to economic issues or student benefits and costs other than an oblique reference to the transformation to "mass education".

Most studies on economic issues in engineering education have focused on quantitative cost factors most evident to faculty members. Several discussions on academic budgets have referred to competing time demands on faculty members in research and teaching, for example Wankat (1999), yet seem to avoid a deeper or more detailed discussion of economic factors. While Snyder (2001) presented a detailed analysis of institutional engineering education costs in an Australian engineering school, his contribution has not
yet stimulated further discussion linking student contributions with economic and wider social benefits. Iyer (2009) provided similar data, in terms of staff hours in an Indian context. Taking a similar perspective Mansmann and Scholl (2007) reported a detailed interfaculty resourcing model for a German university using a simple model of staff contact hour availability, strongly shaped by German state legislation requirements. Each teaching academic was expected to provide a certain number of "semester teaching periods per week" in a strongly government supported system. In this system, student contributions were reported to be small in terms of tuition fees and the state provided most of their living expenses. These studies in engineering schools reflect a similar economic framework used in earlier studies on economies of scale in higher education (e.g. Nelson & Hevert, 1992) and bypass the related issue of education quality.

Some business researchers have examined economic issues in considerably more detail, at least from the faculty perspective. For example, Polonsky, Juric and Mankelow (2003) reported a detailed quantitative study on how marketing academics spent their time, comparing their results with several others in business-related disciplines. However, their economic focus was restricted to faculty members alone and did not consider interactions with students or education quality, other than as a demand on staff time.

Economic changes in universities

The rapid increases in demand for higher education, particularly in industrialised countries but reflected across the world, has focused higher education policy debates on student and family contributions as governments have found it increasingly difficult to underwrite the full cost (Johnston, 2004). Research-led universities in particular have recently experienced acute financial constraints (Johnston, 2008).

Like several other contributors whose work frames this paper, this author's interest in education economics was initially circumstantial. After many years immersed in teaching engineering and researching engineering practice, the author assumed responsibility for managing a education programme delivered by 37 colleagues and rearranging it so it could be delivered by 28 colleagues a year later. As in many other research-led universities in the world, economic resources had moved from funding recurrent teaching expenses into discretionary research initiatives in order to help the institution to compete more effectively for fee-paying students and industrial research funding that tend to follow research-based rankings such as the Shanghai Jiao-Tong University index (Johnston, 2008). Colleagues who had basked for many years in the apparent security of academic tenure were suddenly offered attractive 'separation' options. (Separation, either voluntary or involuntary, has become the preferred institutional euphemism for redundancy in Australia.) Others, who had lived on contracts that had always been renewed, seemingly automatically, suddenly realised that their contracts would not be renewed. With little time to respond, simple crude measures of performance were invoked to decide which of the ‘tenured’ faculty remained. The number of research publications, weighted by a government-imposed publication quality ranking index (since abandoned) was the primary determinant. The number of lectures delivered over the previous five
years contributed, though this was described as the “relative opportunity to perform research”. Distinguished teaching awards counted for a single point.

Johnston (2008) has reported American experiences with similar changes, anticipating significant future rises in student contributions: “it is not clear that society is necessarily better served by universities all struggling to displace one another on some putative prestige ladder with little or no sensitivity to the public opportunity costs .... this market-driven drive for betterment—for higher rankings, greater scholarly prestige, a deeper applicant pool, and a greater market share of top students and research contracts—is a major reason for the elite of America’s colleges and universities being the envy of the academic world. At the same time, this market-driven competition also drives up top faculty and administrative salaries, the institutionally-borne costs of research, and the expensive amenities that attract the most sought after students (and their parents), and thus contributes to the steep upward trajectory of higher educational costs and to the financial fragility of US colleges and universities.”

The strong focus on research as an institutional objective in itself contrasts with an alternate view that dominated universities until the mid-1990s. Research was then seen as a means of retaining the interest and loyalty of leading faculty, a compensation for relatively low salaries largely determined by government funding for a teaching institution (Nelson & Hevert, 1992, p. 481).

At the same time as these resourcing changes, the author’s university adopted a completely new degree structure similar in principle to the European Bologna model (Mansmann & Scholl, 2007; The University of Western Australia, 2008). There were several objectives, including a large reduction in undergraduate degrees (69 down to 4), simplifying course structures to achieve economies of scale, broadening undergraduate education by requiring all students to study outside their chosen discipline, and new teaching techniques to improve learning. Professional faculties were most affected by the change. While law and medicine decided to become graduate schools, the engineering faculty was constrained by government funding to adopt a hybrid undergraduate and graduate programme that requires that every component of the programme to be redesigned (Trevelyan, Baillie, MacNish, & Fernando, 2010). This was a high risk strategy, sharply reducing direct funding for teaching to retain more flexibility for discretionary research funding initiatives, while at the same time implementing a radically new course structure and seeking significant learning improvements. The author’s university is located at the centre of one of the world’s greatest contemporary industrial expansion efforts and future energy wealth perhaps justifies this research-led ambition. Current plans for expansion of petroleum, mining and energy production in the next few years exceed US$ 150 billion in a state with a population of just over two million people.

A case for investment in engineering education improvement?

Many engineering educators and researchers have expressed frustration when writing or speaking about education reform (e.g.Heywood, 2005). Why, they ask, is it so difficult to gain the support of colleagues for education reform when the benefits are so clear? Whether it is problem-based learning, cooperative learning, an integrated curriculum, it is
difficult to gain the active support of colleagues in most education institutions when one is attempting to introduce learning improvements that researchers have demonstrated to be highly effective improvements.

At the same time, engineering academics can readily appreciate the economic imperative when advocating research on technology improvement. We all recognise that a company would be much more likely to adopt innovative technology when it is easy to demonstrate an economic gain. Why, then, do we seem to maintain such a quiet stance on the economics of education and the potential for economic improvement?

It could be argued that few engineering educators are in a position to influence the economic constraints within which they perform their teaching and research, and therefore there is little point in discussing the issue. At the same time, many leading educators have advocated ‘research-based’, ‘scholarly’ or ‘evidence-based’ approaches to curriculum reform but these messages have not yet been widely understood or accepted. An evidence-based economic framework would make it easier, ultimately, to argue for the investment needed in order to achieve reforms like these.

Most industries provide scope for incremental operational improvements without requiring large capital investments. Gradually, however, constraints reflecting limitations ‘designed into the system’ restrict the benefits that can be obtained from incremental improvements. Sooner or later, owners can be convinced to make a major new capital investment in order to obtain a significant economic advantage over other producers.

The relative cost of non-tradable products from engineering enterprises might serve as a broad measure of the overall success of engineering in a national context. Potable water is produced by public utilities that are predominantly engineering enterprises and is mostly a non-traded commodity. The cost to consumers (including indirect costs) varies significantly. Trevelyan (2005) has argued that the cost in some developing countries is many times higher than in industrialized countries and later (Domal, 2010) demonstrated links with inappropriate education priorities in a comparative study of engineering practice in India and Australia. These findings were echoed recently by (Blom & Saeki, 2011) in an extensive study on the perceptions of Indian engineering employers on the appropriateness of engineering education. While the relative cost of potable water reflects the work of engineers over an extended period of time and would not be useful for evaluating short- or medium-term changes, it serves nevertheless as an indicator that not all countries obtain similar benefits from engineering education currently.

There may be a good case for a significant capital investment in engineering education in many countries to achieve a significant improvement in economic performance. Without reliable performance models, however, it will be difficult to reliably forecast the benefits of this investment. Educators will need reliable forecasts to build the confidence needed for governments or other sources of investment capital to commit the necessary funding.

One way to measure the benefits of investment in engineering education might be to measure the enterprise investments needed for novice engineers to achieve a recognised level of professional competence. It may be possible to side-step a debate an appropriate
level of competence by simply measuring the enterprise investment needed during the first two years when the largest gains in novice engineer productivity are likely to be observed.

Recent advances in understanding how people learn have provided valuable insights that will lead to future student learning improvements (e.g. Ambrose, Bridges, Lovett, DiPietro, & Norman, 2010; Bowden, 2009; Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000; Smith, Sheppard, Johnson, & Johnson, 2005). However, these improvements need to be guided by some understanding of the ongoing value of education for graduates. This paper presents some suggestions for future research studies. The questions arising from this discussion provide some interesting issues for engineering education researchers to investigate in more detail.

A few studies on the transition to practice have revealed some of the difficulties they encounter (Martin, Maytham, Case, & Fraser, 2005; Trevelyan & Tilli, 2008) and further studies could help balance discussions on economics by identifying some of the links between education and subsequent behaviours and perceptions of engineers in practice.

Returning to the questions that opened this discussion, we can easily recognise that five years of study imposes significant social and economic costs, not least on students and their families. Workplace graduate training imposes significant investment requirements on engineering enterprises. While it is often difficult to describe the benefits in meaningful terms, education debates could be perhaps be enlivened by more studies on the links between classroom learning, engineering practice and economics.

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Bringing Engineering Education to Life – An Empirical Approach

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Abstract: This paper focuses upon the argument that the role played by the engineering profession within today’s society has changed markedly over the past several years from providing the foundations for contemporary life to leading societal change and becoming one of the key driver’s of future social development.

Coining the term ‘Engineering-Sociology’ this paper contributes to engineering education and engineering education research by proposing a new paradigm upon which future engineering education programmes and engineering education research might build. Developed out of an approach to learning and teaching practice, Engineering-Sociology encapsulates both traditional and applied approaches to engineering education and engineering education research. It suggests that in order to meet future challenges there is a need to bring together what are generally perceived to be two diametrically opposed paradigms, namely engineering and sociology. Building on contemporary theoretical and pedagogical arguments in engineering education research, the paper concludes that by encouraging engineering educators to ‘think differently’, Engineering-Sociology can provide an approach to learning and teaching that both enhances the student experience and meets the changing needs of society.

Introduction – Engineering and Society

Over the past three or so decades, the role played by engineering in promoting societal cohesion and change has shifted from engineering being viewed as ‘the backbone’ of British industry in the 1950’s and 60’s to it becoming a substantive and integral driving force that links society and science in an innovative and forward-thinking manner (RAEng, 2010). Indeed, it may be argued that engineering advances over the past 10 years or so, have provided the impetus for much societal change. This is particularly the case when considering the area of digital engineering and communication, but is also relevant when taking into account the wide range of other engineering fields including power, medical, environmental and materials engineering - all of which have seen innovative advances that have changed the way we live our lives. Yet despite such progress, in many respects engineering has become a ‘hidden’ profession, one which is generally low on the public agenda – only coming to the fore when disaster strikes.
It may be argued that in bringing engineering and society together, the engineering profession acts as society’s glue, innovatively benefitting humanity whilst linking science and society. In the Developed World access to the public infrastructure (communication, transport, modern buildings, clean water, a ready supply of food etc.) is taken for granted by an increasingly ‘media savvy’ population. Yet within this setting, very little thought is given to the engineering innovation, and indeed the engineers behind what, in the UK and elsewhere, has become the ‘expected’ standard of life. Whilst science is generally given a high profile, engineering is generally not on the public radar. Although as a discipline engineering tends to view itself as distinct from science, in many respects in the UK in particular, it has been subsumed into science and is viewed by many (non-engineers) as being a part of science.

The key research question which therefore needs addressing by engineering educators and the profession as a whole is, “How to countermand this trend and promote engineering as a viable, exciting and valid profession – one that can provide young people with an intellectually stimulating and socially worthwhile career“. It is this question that is at the crux of a lot of engineering education research – much of which argues that engineering education needs to change if it is to successfully capture advances in engineering.

**Engineering Education Research – Time for Change**

The valuable role played by engineering education research in guiding and informing engineering education, both in the USA and also internationally is reflected in the literature (see for example Borrego, 2007; Watson, 2009; Borrego & Bernhard, 2011) which, amongst other issues, discusses the role that engineering education research can play in increasing student numbers (Borrego & Bernhard, 2011) and the importance of applying research findings to practice (Watson, 2009). Other previous work has discussed the difficulties encountered by engineering educators in undertaking pedagogic research. Wanket at al. (2002) identify conceptual difficulties experienced by engineers in learning and teaching research noting that problems with ‘sampling’ reflect the fact that students are far more complex to categorise than the more tangible variables engineers are used to working with in their discipline-specific research. Other aspects of pedagogic methodologies are also given attention in the engineering education research literature, with particular attention paid to problems experienced by engineers in identifying suitable approaches and tools with which to investigate learning and teaching approaches (Borrego et al, 2009). It is the questions relating to quality and rigour in engineering education research that continue to drive attempts to improve quality in engineering education today and ultimately the enhancement of students educational experiences (Borrego, 2007; Borrego & Bernhard, 2011).

Previous literature has identified the value of collaboration as being integral to improving the quality of global engineering education research (see for example Borrego & Newswander, 2008). Whilst the empirical and pedagogic value of collaboration cannot be disputed, pedagogically it is important that engineers remain the driving force behind engineering education research (Borrego & Bernhard, 2011). Yet, whilst it is crucial that
engineers take the lead in engineering education research, in order that the discipline is able to deal with the issues faced by contemporary society, it also important that in doing so engineering education research practice is expanded to include a wide range of methodological concepts and approaches (Borrego et al, 2009; Case & Light, 2011).

In many respects it would seem that engineering education and engineering education research is at a crossroads. It is the right time for engineering education to be recognized and lauded internationally, not only for the quality of research being undertaken within the field of engineering education research, but also for the contribution being made to the wider pedagogic field in terms of both theory and practice. Yet, whilst there is much excellent work being conducted within the engineering education research community – engineering education research has not yet developed its own paradigm (Wiedenhoft, 1999; Godfrey & Parker, 2010). It is this gap that the Engineering-Sociology paradigm has been developed to fill.

**Scholarship in Engineering Education**

Previous work by one of the paper author’s (Clark, 2009) proposed a learning and teaching approach developed to promote and enhance the student experience within engineering education. This proposition is:

\[
\text{Relationships + Variety + Synergy = Environment for Success (R + V + S = Success)}
\]

Developed to address the overall pedagogical aim of student (and staff) success, the above proposition recognizes that one of the main challenges faced by engineering educators today is how to create a learning environment in which such success can be nurtured and achieved. From this perspective there are three key components necessary to engender such an environment.

Crucial to the learning environment, Relationships [R] are key to successful learning – as such they need to be valued and nurtured (Cowan, 2006). Relationships in the learning environment reflect the complexities of the social networks encapsulated within and across educational settings. As such, different types of relationship exist between students and their peers, students and teachers, amongst colleagues and between those in education and other stakeholders including families, employers and policy makers. Previous studies have suggested that relationships play a vital part in addressing issues of retention by promoting a ‘sense of belonging’ (see for example Read et al, 2003).

Variety [V] in learning and teaching reflects the need for engineering educators to adopt an innovative approach. Whilst current trends tend to associate innovation with technology – it is evident that as a concept, Variety can incorporate so much more. Indeed, variety within the learning environment can include a range of different learning and teaching approaches including active learning, work-based learning, project and problem-based learning, to name but a few. Whilst it is imperative that all learning and teaching should be contextualized within a discipline-specific setting (Prosser & Trigwell, 1999) engineering is in a fortunate position in that it can provide numerous opportunities for
engineering educators to introduce variety into the curriculum (laboratories: work-based learning: project-based learning: tutorials etc).

The third component, Synergy [S], captures the concept of constructive alignment (Biggs & Tang, 2006), but further develops this approach so as to encapsulate the requirements and expectations of a wider group of stakeholders including professional bodies, industry and wider society.

In introducing and then evaluating the RVS approach to learning and teaching (Clark, 2009), a new paradigm in engineering education has emerged. This paradigm (Kuhn, 1962) which encapsulates engineering epistemologies and pedagogies within a sociological context has been termed Engineering-Sociology. It is this proposition that has been adopted as a foundational framework in responding to the earlier research question.

**Engineering-Sociology – A New Paradigm for Contemporary Engineering Education Research**

In the process of critically evaluating the pedagogic value of the RVS approach, it became apparent that there was a real need for a paradigm shift in engineering education and engineering education research. One of the most important considerations in developing the approach was the need to take account of apriori knowledge, practice and understanding in engineering education and engineering education research (Borrego et al, 2009). The RVS approach contextualises engineering within its wider social setting; in doing so it brings together two seemingly diametrically opposed academic paradigms, Engineering and Sociology, into a single approach. Coining the term 'Engineering-Sociology' this paradigm firmly embeds engineering education and engineering education research into the wider social context. It reaffirms the role of engineering as being a key driver of societal change and innovation (Vanderburg & Khan, 1994), whilst providing the means by which engineering educators can frame empirical research into engineering learning and teaching practice and policy.

Given that sociology is likely to be an ‘alien’ field to many of this paper’s readership, it is important to define what is meant by the term sociology. For the purposes of developing the Engineering-Sociology paradigm the American Sociology Association definition of sociology was used: Sociology is the "study of society: a social science involving the study of the social lives of people, groups, and societies: the study of our behaviour as social beings, covering everything from the analysis of short contacts between anonymous individuals on the street to the study of global social processes: the scientific study of social aggregations, the entities through which humans move throughout their lives: an overarching unification of all studies of humankind, including history, psychology, and economics" (ASA, 2011). To put it simply, sociology represents the ‘study of society’. In introducing a new paradigm, that of Engineering-Sociology, the importance of ‘engineers’, ‘engineering’, ‘engineering education’ and ‘engineering education research’ to society is both acknowledged and promoted. Moreover, by accepting the integral role played by engineering in advancing and supporting society, the paradigm logically leads to the suggestion that engineering education researchers should familiarise themselves with the wide range of sociological...
methods, paradigms and concepts available with which to empirically investigate and so enhance engineering education.

Engineering and sociology are not natural ‘allies’. Indeed, whilst previous (and perhaps current) generations of engineers may have argued that sociology is not an empirically grounded field in the same way as engineering or science, some social scientists are equally negative about engineering suggesting that as a discipline, it cannot be defined as a ‘true profession’ because engineers are not necessarily ‘autonomous’ (Perucci & Gerstl, 1969; Ritti, 1971; Rae & Volti, 2001; Volti, 2008). It is therefore evident that, for the benefit of society in general, and engineering education in particular, much work needs to be done on both sides to breakdown long held and potentially damaging assumptions and stereotypes.

In developing the Engineering-Sociology paradigm, engineering has deliberately been prioritised in front of sociology. In doing so the paper authors acknowledge the fact that engineering education and engineering education research is essentially about engineering and, as such, must be led by those best placed to inform and shape the field (engineering educators).

Evidence

The description of this approach as empirical is wholly relevant. Developing learning and teaching practice and scholarship that aids both student and teacher in ‘making sense’ of the engineering profession in an ever changing world was initially based on experience and observation. The proposition emerged and in exploring ways to gather evidence that the proposition has value, the inclusion of the sociological perspective challenged the authors to view engineering education and engineering education research in new ways.

Initial evidence of application and evaluation is reported elsewhere (Clark, 2009; Clark and Andrews, 2011) and is at an early stage. This paper is focused on the articulation of the paradigm, a paradigm that is perhaps more organic than the developing trend towards curriculum design based predominantly around competences.

Concluding Remarks

In developing and evaluating the RVS approach to learning and teaching in engineering education – and in proposing the Engineering-Sociology paradigm built on this approach, the paper authors have taken account of the depth of previous literature analysing and theorising engineering education and engineering education research (see for example Wiedenhoeft, 1999; Wanket et al, 2002; Borrego, 2007; Borrego et al, 2009). Although engineering is deliberately given precedence over sociology, the collaborative nature of the paradigm should not be undervalued. Both engineering and sociology are vital components of the paradigm, and each needs to be considered concurrently.

In conclusion it should be noted that the ideas expressed in this paper result from a professional collaboration between an engineer and a social scientist. Whilst this collaboration is on the whole very positive and mutually beneficial, it has not been without
its difficulties and misunderstandings. Indeed, the fact that engineering and sociology are built on very different conceptual, epistemological, ontological and linguistic groundings makes such a collaboration a constant challenge but a challenge that is both academically enriching and professionally demanding. Yet by encouraging engineering educators to ‘think differently’ about engineering education and engineering education research, it is anticipated that the Engineering-Sociology paradigm will provide engineering educators with the means by which engineering education can begin to meet the ever changing demands of 21st Century society.

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Threshold capabilities: an emerging methodology to locate curricula thresholds

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Abstract: Threshold concept theory is an important recent advance in discipline-based Higher Education research. The theory proposes that within disciplines there are critical concepts that are both transformational and troublesome for students. By identifying and investigating these concepts it is possible to focus curricula. This paper describes a methodology to identify and investigate threshold concepts, which is then developed and tested in a global study. The methodology involves two major phases: identification of potential threshold concepts using interviews and focus groups with students, tutors, and academics discussing thresholds in one unit or discipline; and negotiation across unit, disciplinary, institutional, and eventually international boundaries.

Introduction

The improvement of engineering curricula to ensure understanding and encourage deep rather than surface approaches to learning requires careful design. Threshold concept theory is an important recent advance in higher education with potential to provide a framework to achieve this.

Within the theoretical framework it is proposed that many courses have “threshold concepts” that are transformative for students, critical to students’ progress, and troublesome for many students (Meyer & Land, 2003). By identifying and investigating these we can focus otherwise crowded curricula onto these concepts, therefore ensuring students pass through the thresholds to future learning (Cousin, 2006).

Academics at our university have developed and tested a methodology to identify and investigate threshold concepts, and are leading an international project to establish an approach to enhance engineering curricula using threshold concept theory. We have tested the methodology by identifying and investigating threshold concepts within the first two years of any engineering course. International partners include Lund, Oxford and Birmingham Universities.

Previously, many diverse methods have been used to identify and investigate threshold concepts. Researchers have undertaken interviews, phenomenography, laboratory observations, mixed methods including quantitative surveys, and analysis of distributions of grades (Baillie & Johnson, 2008; Holloway, Alpay, & Bull, 2010; Kabo & Baillie, 2009;
Scott, Harlow, Peter, & Cowie, 2010). However, a clearly designed, described and tested method is required. This paper addresses the following:

*How can threshold concepts be identified and described in a broadly defined discipline?*

The theoretical framework is introduced below. The main focus of the paper is a description of the methodology we have developed, the consultative process of developing the methodology, and outcomes of our experience testing the methodology to identify and investigate threshold concepts required by engineering students during first and second year.

The method we have developed will be useful to curriculum renewal in engineering and other disciplines, especially broad interdisciplinary courses.

**Theoretical framework**

Threshold concept theory is an established theory forming the framework for our study. Threshold capability theory (Baillie, Bowden, & Meyer, forthcoming) is a new development, found to be useful in this study. It combines threshold concept theory with capability theory including variation theory.

Threshold concepts are transformative and troublesome for students (Meyer & Land, 2003, pp.8-9). They are usually irreversible, and integrative meaning that they connect concepts. Many threshold concepts enhance students’ use of language. Threshold concepts can be troublesome for reasons such as being inert, ritual, conceptually difficult knowledge, foreign or alien (Perkins, 1999, pp.8-10).

Capability theory proposes that university students should prepare for unknown futures, such that graduates can identify key aspects of a situation, relate these to other knowledge, determine the task or problem, design a process to deal with it, and have ability to complete this (Bowden, 2004, p.40).

Variation theory describes how students learn by experiencing variation (Bowden & Marton, 1998). This can be achieved through multiple examples changing in one dimension at a time. The students must be given the opportunity to experience the differences between the different examples.

Baillie, Bowden and Meyer propose a merging of threshold concept theory and capability theory into Threshold Capability Theory and argue that capability and variation theories provide the ideal mechanism for developing a strong pedagogical approach based on the newly emerging knowledge of the attributes of threshold concepts within different domains. With the emergence of Threshold Capability Theory we broadened our study from threshold concepts to also allow for threshold capabilities. This proved to be valuable in our experience testing the methodology, and alleviated concerns about the definition of “concept” raised by many participants. By investigating knowledge capabilities to act effectively for unknown futures, rather than concepts only, we were able to consider tools such as vectors, which many academics did not regard as concepts.
New Methodology to Identify and Investigate Threshold Concepts

Purpose

The purpose of our application of the methodology was to identify and investigate threshold concepts in the first and second year of any engineering course. The methodology was tested to develop a new engineering curriculum. A key criterion was to identify threshold concepts applicable across existing engineering units and disciplines. This was expected to help create a more inter-disciplinary course and help students better understand the overarching concepts and the relationships between concepts, and experience the variations that enhance understanding as recommended by variation theory. The methodology will be relevant to educators generally as part of an approach to curriculum renewal.

Whether a concept is a threshold is determined by the students’ experiences. However, the reasons a concept is threshold for a student could be related to features of the discipline, the student, or the curriculum including any feature of the learning experience. The methodology was developed to identify thresholds concepts, and also possible reasons they might be seen as thresholds.

Development of the Methodology

The method was developed by considering potential sources of data and the best ways to collect and analyse data. The method was discussed by the researchers at our university in consultation with the Project Reference Group and international collaborators.

Meyer (personal communication) identified two non-negotiable features of threshold concepts: all threshold concepts are transformative ontologically and epistemologically. Threshold concepts are features of students’ experiences and can be layered such that the core threshold concept is not always clear. Our methodology was therefore designed to focus on students’ experiences and to iteratively investigate more deeply each threshold. We identified engineering students and engineering teachers as having experience that would help us to understand which concepts are threshold concepts.

The Method

Participants

Data were collected from engineering students, engineering academics, and first year tutors. Details of protocols, questions and participant demographics are published separately (Male & Baille, 2011). Qualitative methods allowed the depth necessary to investigate the core thresholds underlying troublesome concepts. Students, academics, and tutors provided different perspectives. Academics understand the concepts they plan to teach and why they are important for future parts of a course. They glean understanding of students’ experiences from students’ questions and from assessments. Students have experiences of concepts they found troublesome and that have felt transformative, and by third and fourth year are able to identify first year concepts that
they found transformative. Tutors have understanding from their own recent experiences as students, are aware of students’ experiences based on interactions in tutorials, and see evidence of misunderstanding in assessments.

**Overarching plan**

The progress of the research centred around an evolving inventory of threshold concepts. The method has two phases. In the Diverging Phase, students, tutors, and academics identified and discussed potential threshold concepts based on their teaching and learning experiences in one unit or engineering discipline. In the Integrating Phase, students and academics interacted, facilitating discussion of concepts between people with diverse perspectives. The Diverging Phase necessarily began first as data from the Diverging Phase provided a starting point for discussion in the Integrating Phase. However, after several pages of potential threshold concepts had been identified from the Diverging Phase, the two phases continued, supporting each other.

All data collection events began with an explanation of threshold concept theory and the project. This was designed to help establish faith in the project and to help the participants to provide relevant data.

Similarly, at all events relevant threshold concepts already identified were presented to participants. This was designed to address Meyer’s (personal communication) prior warning that it is necessary to recognize compounding troublesomeness and uncover the core threshold concepts. Each event probed more deeply rather than remaining at the level of initial thoughts.

**The Diverging Phase**

Initially, potential thresholds were identified in specific units or engineering disciplines. This phase used qualitative methods suitable for the participants. The phase is important as it is the opportunity to ensure critical and comprehensive thinking. Critical thinking is necessary because threshold concepts could be concepts that are not normally recognized as part of an engineering syllabus. They could be concepts that are tacit for academics. Examples are the directions in bending moment diagrams and shear force diagrams and the physical meaning of a circuit diagram. Furthermore, there are threshold concepts that have not been in traditional engineering courses. Examples are “Poverty” and “Development”. The diverging phase is designed to collect all potential threshold concepts.

Interviews were held with academics to identify and discuss concepts based on their teaching of specific units in specific engineering disciplines. Academics were asked to discuss their units, potential thresholds, reasons they perceived these to be thresholds, and possible ways to teach them.

Focus groups and workshops were considered less confronting than interviews for students. In a focus group and a workshop, students were asked to identify potential thresholds they had experienced, and describe how and why they were troublesome. Tutors were interviewed in focus groups to identify potential thresholds experienced by students and discuss reasons they thought they were thresholds.
Workshops with academics and some postgraduate students at other locations also contributed to the Diverging Phase. These occurred at Birmingham, Oxford and Lund universities in Europe, the University of Auckland (New Zealand), Western Australia, South Australia, and Melbourne.

Participants were introduced to threshold concept theory and the project, and asked to identify potential threshold concepts, why they felt these were thresholds and how they could be taught.

All events were semi-structured, with planned questions, and probing questions. Events were usually one hour, and ranged in duration between 30 and 90 minutes.

**The Integrating Phase**

The second phase of data collection allowed for negotiation of the concepts and investigation of threshold concepts underlying identified concepts. Interaction between participants with diverse perspectives was critical. Conversations in the following groups were valuable: between students from different disciplines and years of study, between students and academics, between academics from different specialties within one engineering discipline, between academics in different engineering and science disciplines, and between academics from different universities. In our project, this phase has been undertaken in a student workshop, a student-staff workshop and regional workshops around Australia among academics from multiple engineering disciplines, mathematics, physics, and computer science. These discussions allowed identification of concepts that cross disciplinary boundaries and understanding of variation between the approaches in different disciplines.

Participants worked in groups and negotiated potential thresholds already identified and any others they identified. Using handouts, participants were asked whether they considered potential thresholds to be thresholds, why, and how students could be helped to overcome the thresholds.

The regional workshops were designed over virtual meetings with our UK collaborators. They were attended by academics who had taught engineers, from multiple universities. They focused on the Integrating Phase. However, the opportunities to collect data from many people in a short time were optimised, including further contribution to the Diverging Phase. Participants were sent an email with a link to the project website, inviting them to start thinking about concepts that are transformative and troublesome. On arrival participants were given a handout asking them the questions normally asked at events in the Diverging Phase. Groups were designed to be either inter-disciplinary or within one engineering discipline. Mathematicians and scientists were distributed around the groups.

At the regional workshops, overarching facilitators were complemented by, where possible, a process facilitator and a disciplinary facilitator at each table. After the introduction about the project and threshold concept theory, participants worked in groups. Workshops were four hours in duration. Before the break and before the finish,
groups reported to the room. Participants were encouraged to talk with people from other tables during the break to enhance the integration.

Group facilitators were prepped before the workshop. Meyer (personal communication) had reported that at similar workshops in other disciplines, theoretical discussion occurred outside the purpose of the workshop. Table facilitators focused discussion on the required tasks, asked probing questions, engaged all participants, and limited discussion about threshold concept theory by “parking” theoretical issues until they could be addressed by an overarching facilitator. Disciplinary facilitators ensured that discussions were summarised on the handouts. Process facilitators took notes on the progress of the discussion, including participants’ responses to the method and the theory.

**Data collection and analysis throughout both phases**

Data were collected as part of the methodology, and also to evaluate the methodology. This section discusses data collected as part of the methodology. During interviews and focus groups the researcher made observations and notes. Discussions were recorded if consent was granted. At the student and student-staff workshops, the conversations involving the whole room were recorded. At the regional workshops, all discussions were recorded with a device on every table. Recordings were transcribed, unless background noise was excessive. Workshop groups also responded to questions on handouts.

The evolution of a threshold concept inventory is central to the methodology. Content based analysis identified threshold concepts, their transformative and troublesome features, and possible ways to help students overcome them. Consequently an inventory of threshold concepts, their features and possible ways to help students overcome them was developed iteratively. Each item includes sufficient description for engineers to identify the concept, relevance in the course or engineering practice, ways the concept can be troublesome, and ways to help students understand the concept.

At each stage, relevant parts of the inventory to date were presented to each new group of participants. This ensured increasing depth and effective use of participants’ and researchers’ time. For example, academics were shown potential threshold concepts identified in their fields early in their interviews.

As far as practical, participants were given opportunities to correct misunderstandings evident in iterations following their contributions. This improved validity, and helped maintain trust and support. For example, academics were sent the relevant potential thresholds they had identified, or iterations made in response to their comments. Similarly, students were sent the concepts they had raised in the student workshop, before they were discussed in the student-staff workshop.

**Evaluation of the methodology**

Data collected to evaluate the methodology included responses on workshop evaluation forms, and process notes taken by the process facilitators at the regional workshops. The evaluator, John Bowden, took a formative approach, attending project meetings, attending
the first regional workshop, designing open questions for the evaluation form, and analysing these forms. A debrief was held with the project team, collaborators, and the process facilitators following the first regional workshop.

Different groups of participants provided different kinds of data. For example, academics raised high level concepts such as “Abstraction”. In contrast, students raised specific difficulties such as the “k axis”. Tutors identified misunderstandings among first year students, sources of these, and how it can feel for a student to be baffled by a misunderstanding arising from a subject in which they previously enjoyed prowess. Overcoming these misunderstandings would be epistemologically transformative.

An achievement of the methodology has been gaining trust among academics. This is critical to curriculum development. Academics were initially wary of developing curricula based on new rather than established methods. Shifts in attitude were apparent during interviews. Our experience fits Cousin’s (2010) experience that threshold concepts engage academics. We also found that the suggestion of threshold capability theory alleviated some concerns. It weakened the significance of a definition of a “concept”, and provided a way to help students overcome thresholds.

At the regional workshops, facilitators at the tables were valued by participants in the feedback. Process facilitators’ notes were consistent with the following observations made by Bowden, which also note the shift from skepticism, and the significance of variation theory.

Initially, some participants were somewhat defensive and dismissive... Quickly the discussions became more constructive... There was considerable cross-disciplinary questioning and this was aided by the contributions of the process leader and content leader assigned to each table. Their role was commented on favourably in the evaluation reported later. (Bowden, 2011, p.3)

[After the break] there was still some difficulty in coming to an agreement about just what was the threshold in any particular case or whether the stated threshold on the list actually comprised more detailed sub-concepts that were the candidates for the actual threshold concepts. In contrast there were groups that had focused on over-arching thresholds that might not be threshold concepts but that are tools through which we see the world. "Vectors" was suggested (Bowden, 2011, p.4)

This illustrates how the Integrating Phase allowed negotiation of thresholds. "Vectors" was considered to underlie previously identified potential threshold concepts such as: acceleration in curvilinear motion, and representing angular motion as a vector using the axis of rotation. Additionally, “Conservation Principles” was seen to overarch conservation of energy, mass, momentum and charge.

Conclusions

We have developed and tested a method of identifying and investigating threshold concepts in a broadly defined course. The method entails interviews, focus groups and workshops with students, tutors and academics in two stages: a Diverging Phase in which
potential threshold concepts are identified within individual units and disciplines and an Integrating Phase in which these are negotiated across units, disciplines, and institutions. Our methodology can be used to identify and investigate threshold concepts as part of curriculum development, especially where integration of previously distinct fields of study is desired.

The threshold concept inventory will continue to evolve as students, teaching methods, learning environments and demand for learning outcomes change. Further research questions are emerging around differences across universities with different student demographics, and identification of why thresholds are troublesome: features of students, teaching, or subject differences.

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Papers which are not presented in REES 2011

Adapting Engineering Education for a Mindmap-Based Digital Textbook: To reduce the skill gap between what the industry demands and what academia delivers

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Abstract: This paper describes a novel and interactive tool for teaching and learning (the Mindmap-Based Digital Textbook: MindBook) that allows teachers and curriculum designers to generate a mindmap-based digital textbook when creating content for technology and engineering subjects. Mindmap is often used amongst educational and non-educational aspects however very little research has been attempted to use a mindmap concept for creating digital textbook. We introduce an alternative courseware technology and pedagogy that allow a larger number of educators or industrial experts to develop, classify and organize multiple topics for digital textbooks whilst maintaining its user friendliness. The main purpose of the tool is to reduce the skill gap between what industry demands and what academia delivers. We implement a prototype and perform a user study to investigate its efficiency and flexibility as a potential digital textbook for engineering education. A user study shows that this new model has great potential to enhance the teaching and learning approaches.

Introduction

Students need a good foundation in technology and engineering education as it is essential to contemporary environment where technology and engineering based industries are considered as one of the major driving forces in the world economy (Riojas et. al., 2010). Engineering education requires the application of content knowledge and cognitive processes in order to identify technical problems systematically. This helps the students to analyze and select appropriate methods for complex systems in order to satisfy societal demands. Students will need to develop a deep understanding of fundamental engineering principles at the K-12 levels as well as at the college level so that they are able to pursue a wide range of engineering and technical opportunities (Brophy et. al., 2008).

Our research seeks to propose and experiment using a novel and interactive authoring tool for teaching and learning, namely MindBook (Mindmap-Based Digital Textbook) that
allows teachers and industrial experts to generate mindmap-based digital textbooks collaboratively.

Mindmap is a visualization tool that allows users to generate, organize and structure information via creating concept nodes (Calvo et al., 2009; Dagez and Hashim, 2007; Willis and Miertschin, 2005). The advantages brought about by the usage of concept maps have been highlighted by Joseph Novak (1984); while the usage of mindmap has been advocated by Tony Buzan (1993). Mindmap can assist in describing the context of a document collection or recreating a particular topic by allowing students and teachers to incrementally generate structure and correlate information collectively in order to enable collaborative problem solving.

Although it is a powerful tool, little research effort has been done on information extraction from mindmap for enhancing other applications (Beel et al., 2009) such as digital textbooks. Our work provides the advantage of knowledge sharing among students as well as collaboration among authors (such as Wikibooks) through digitizing information into a collection such as a school digital library.

MindBook that we developed enables students to preview and overview what they will learn and what they have missed through the mindmap based digital textbook. MindBook also helps students to acquire knowledge by integrating relevant resources such as texts, video and images with its various elements. This allows the creation of a new generation of digital textbooks by facilitating the sharing of learning contents amongst students. A user study was conducted to investigate common problems and issues that authors face while creating mindmap-based courseware and hence, we propose strategies to overcome some of the authoring problems.

Throughout the remainder of the paper, we focus on the four main processes involved in designing engineering curriculum using MindBook: 1) Preparation of topics, resources, modules and levels; 2) Development of metalinks based on a particular subject or topic using mindmap; 3) Insertion of learning resources into mindmap; and 4) Providing grade levels for topics.

The Curriculum Design for Engineering Education

Students no longer receive their education only through the traditional methods of lecturing and textbook learning (Fortier et al., 2002). For example, as the requirements of the stakeholders (such as industrial experts) in the engineering education have changed, Central Queensland University suggested a new curriculum design for engineering education. This includes (Hosseinzadeh and Senini 2007):

- ensuring course content is relevant and up-to-date
- collaborating with industry to ensure undergraduate projects have a real-world basis application
- developing cutting-edge learning facilities and resources that are congruent with industry conditions.

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The dynamic nature of the engineering industry creates a set of circumstances that make it extremely difficult to obtain this level of experience before technology becomes out-dated. Therefore there is a need for the re-development of the school engineering pedagogical curriculum and educational system to reduce the skill gap between the industry demands and what is delivered. However it is difficult to find resources necessary for staying technologically up to date as well as to correctly forecast what is needed coming years. And many schools do not have the expertise or resources needed to improve their engineering education system.

Therefore, it is necessary to create teams of curricula designers, where experts of the field can cooperate to create adequate curricula. Figure 1 shows an example of a team of curricula designers.

Designers for curricula are either subject matter experts in their particular field of the curriculum with deeper knowledge of learning theories, learning taxonomies, or they are industrial experts with a good background in their own fields but with little knowledge of how to teach it to others. Teachers also can contribute to MindBook by creating their own content. In this way the content and skills being taught in the courses can be aligned with what industry needs, but it is also important that the quality level of these skills should be at a satisfactory level. Where specific skills are currently being taught, evaluation should be conducted once the students have completed the course prescribed by the industrial expert.

However when specialists work together there are communication problems. Thus, it is crucial to introduce tools that facilitate cooperation to develop the curriculum together. In order to account for this, MindBook was created using mindmap techniques and web technologies which supports Computer Supported Cooperative Work (CSCW) to enhance
the collaboration between all members in order to ensure the cohesion of their objectives and monitors their progress.

**Implementation**

MindBook is a novel mindmap based digital book and authoring tool which contains a collection of topics, learning modules and resources. A well-defined MindBook can be a digital textbook itself. The tool is represented in graphic form as a mindmap (Figure 2). Our digital textbook data model was adapted from the industry standard topic maps data model (Özsoyoglu et al., 2004; Ozel et al., 2004) and modified to be tailored into our model. It is structured as follows:

- **Topics**, which are included via creating nodes. Each topic must have a unique name.
- **Metalinks**, which are relationships between topics (which constitutes hierarchies between topics, linking related nodes with connections),
- **Modules** which are paragraphs or sections consist of learning resources. In our project we implement in a form of a flash based flip-book,
- **Questions** which infer the level of the students’ understanding from the results of answered questions.
- **Resources** which are parts of the modules (e.g. text, video and figures, etc.,), and
- **Levels** of academic achievement.

The MindBook we have developed was originally designed as an authoring tool to create digital textbook which is specifically designed to replace the traditional textbook. As mind map requires visual cues for its implementation, we customized FreeMind (FreeMind, 2010) which is an open source software as part of our mind map design.

Figure 2 illustrates an example of the MindBook. A different way of structuring and visualizing contents is possible by creating and inserting nodes. It also allows users to add hyperlinks at an internal/external learning resource such as a local file or a web address.
MindBook consists of three types of file: a mindmap file, an XML file, and learning resource files. A mindmap file describes the structure of a tree, which has color, font, size and location attributes of its nodes. A XML file has chapters, sections and questions as its nodes, and the connections between related nodes. It defines the sequence in which sections of the learning modules are displayed in digital textbooks, and it contains the path of learning resources and the level of understanding. Learning resources are text, image, movie or hyper link format. The level icons (1-12) on the toolbar that runs down the left hand side of the tool include level priority such that they can be used by the authors as an important direction in the development of a proper learning model. Icons (1-4) are given by textbook publisher (professional textbook authors), icons (5-8) are used by lecturers/teachers and icons (9-12) are inserted by industrial experts. If a topic has many icons, it will be considered as important by different authors. If the level of knowledge is equal to or higher than the threshold (for example 9) which is considered an important topic in a real-world, a real-world basis application can be run in accordance to an industrial expert.

Each XML file is equivalent to one digital textbook. The digital library manages the information about all digital textbook that are being created. The overall structure of the authoring tool is shown in Figure 3.

![Figure 3: Overall structure of the authoring tool](image)

**User Study**

We have used MindBook to generate digital textbooks collaboratively for the engineering curriculum. We performed a study to investigate the usability of the tool. 29 authors (20 lecturers, 5 industrial experts, 2 instructional designers and 2 multimedia developers) in the field of curriculum development participated in our survey. We gave them a short tutorial, demonstrating how edit the mind map and its’ resources. After the tutorial, they were asked to insert 5 new topics and 3 resources for their topic and level. The participants were required to set proper attributes (resources) on the node they newly
inserted. After finishing each of the assigned tasks, they were asked to evaluate the ease in accomplishing the task. We also measured the time it took for them to complete all of the tasks. At the end of the evaluation, we conducted a questionnaire to the participants.

**Analysis**

Teachers/lecturers who create maps for the course they teach did not have problems in selecting the appropriate learning topics and resources when we gave task. However multimedia developers and instructional experts were not familiar with the whole subject, therefore they had difficulties in structuring the relationships between topics and classifying learning resources.

**Identifying Topics**

Authors can add any number of branches and sub-branches to a MindBook to represent different topics. There are no rules to limit the authors to use specific information for describing content. Various vocabularies make it easy to create information but shift the load of interpretation to the users.

Among the principal problems with naming topics are:

- Lack of standardization
- The topic titles may not be informative enough

These problems are related to browsing and searching for topics and relevant learning resources. An example in this context is the use of different titles to represent the same topic. A search for “data” will not pick up topics named with “information”. We conclude that we have to define the core set of topics that students should learn before developing a curriculum. Guidelines for authors for choosing topic name have to be distributed as well.

**Constructing relations**

The hierarchy (parent-child) reflects the sections-subsections which is established by the traditional textbook organization and reflects MindBook authors have to follow same hierarchy. The surveyed users had difficulties in deciding what type of relationships to use for linking the nodes. They generally try to follow the content structure of the school textbook. But if they adhere to the national or school curriculum, they might not generate own topic node and continuously refine the learning structure.

The order in learning content classifications is often subjective and arbitrary and could easily be reversed by curriculum designers. Predefined generic relationships of the topics can be suggested but it could be modified, for example, by industrial experts who have good experience and knowledge.

**Classifying learning content**

Users (curriculum designers) can add learning resources such as image, movie clip, questions etc. The content of digital textbooks is one of the most crucial components. In
general, the classification of learning content is based on the author’s knowledge and the content resources which are available to authors.

Learning Content DB (Figure 3) can be defined as a system that is used to create, store, use and reuse learning content. It could be school system or school district information system or nation-wide information system. If national DB is not available to the curriculum designers, they may have to use contents taken from the internet or CD-ROM media which may face various copyright issues. In order to disseminate educational materials through a comprehensive and efficient outlet, the construction of a central learning content DB should be implemented. Nationwide and instantaneous sharing of learning-related materials and information among curriculum designers must be a key ability for creating the digital textbook together. Therefore Learning Content DB needs to be developed to ensure both quality and quantity of contents up to the standard level and guidelines must be established for contents sharing.

**Identifying Levels**

The node has a knowledge level by adding a grade level. In a typical learning structure (learning model or course guide) is laid out in a tree-like structure of course topics (where you are, where you have been and where you are heading). However, identifying knowledge levels of certain topics may be subjective and arbitrary and could easily be reversed. And different countries may use different curriculum. Therefore, once again guideline for the knowledge levels of topics has to be shared by curriculum designers or authors but it could be modified.

**Conclusion**

In this paper, we propose a mindmap based digital textbook and authoring tool for engineering education. We implement the interactive textbook interface with clear layout and structure. The MindBook provides several functions: constructing mindmap, learning resource links and textbook generation. We confirm that learning modules and textbook can be easily created by using the authoring tool we have developed and the created textbooks can be saved in digital library. By using a web-based mindmap, combined authors can contribute to create textbooks.

We performed a user study to investigate its efficiency and flexibility as a potential authoring tool. A user study shows that this new model has great potential to enhance teaching and learning approaches. MindBook is able to show users where they are, where they have been and where they are heading. The knowledge that students have to learn is evolving therefore Mindbook can assist in overcoming the limitations of today's digital textbook applications which are lacking in group collaboration and guidance.

The most important implication of this study is that it is exposing possible problems when curriculum designers work together. By providing them with an opportunity to interact with innovations in course design, teaching methodologies and learning resources we hope students have the skills, knowledge and confidence they need to stimulate their interest for engineering as a possible career.
References


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Student behavior trends in an engineering program

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Abstract: This paper reports outcomes results on an investigation into the behavior trends shown by the students enrolled in the telecommunications engineering degree of the University of Zaragoza. We examine the correlation between data about the students’ behavior and the process of implementation of an innovative learning system carried out in the faculty. On the one hand, the contribution is founded on the results of the self-assessment process fulfilled by students throughout the current and the last four academic years. On the other hand, a project of design and implementation of active learning techniques has been developed in the telecommunications engineering degree at the faculty. The progressive introduction of the active learning strategies was scheduled between the academic years 2005/06 and 2008/09. By comparing both sources of information, students’ behavior patterns can be explained and corrective measures can be taken.

Introduction

In this paper we analyze the results of a research into the students’ behavior trends in the context of the 3-year degree in telecommunications engineering offered at the Engineering Polytechnic School (hereafter referred to as E.U.P.T.) of the University of Zaragoza at Teruel, Spain.

The investigation looks into the correlation between data about the students’ behavior and the progressive process of implementation of an innovative educative system, based on active learning initiatives, carried out at the E.U.P.T. By comparing both sources of information, certain students’ behavior patterns can be explained and corrective measures can be taken as future actions.

The contribution is based on the results of the self-assessment process carried out by students since the academic year 2006/07. Data were collected in the context of a questionnaire handed out at the end of every semester among the students enrolled in

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every course taught at the University of Zaragoza. The survey includes a set of questions aimed at assessing their attitude as students. We have been dealing with data fulfilled by students enrolled in different subjects of the 2nd and 3rd year of the program of telecommunications engineering (semesters 3rd to 6th).

An institutional project of design and implementation of innovative learning techniques has been developed in the telecommunications engineering degree at the E.U.P.T. This global introduction of active learning strategies was progressively scheduled between the academic years 2005/06 and 2008/09. In the context of the University of Zaragoza, the E.U.P.T. has been a pioneering faculty in the implantation of active methodologies into the academic programs.

In this research work, we have assessed the negative aspects of an educational experience by correlating the trends derived from the responses to the questionnaires with the schedule of implantation of the active learning initiatives into the courses. In so doing, we try to give a realistic point of view of the scenario and to obtain valuable guidelines for further actions.

**Context**

The engineering curricula offered by the University of Zaragoza have undergone significant revisions to reflect the integration of the new methodological strategies into their programs. Under the auspices of the University authorities, different activities – seminars, conferences, grants, etc.– have been carried out in order to promote the use of the active learning approaches in the classes. At the E.U.P.T. we rely on a learning model in which the instructor moves from ‘sage on the stage’ to ‘guide on the side’ (King, 1993). The directive staff of the E.U.P.T. has promoted the development of actions of innovation and educational improvement for several years. Activities carried out by different management boards and by teaching committees of the University of Zaragoza have involved both lectures and students.

Several sources have propounded the advantages offered by considering more active methodologies in order to acquire the skills and competences that students will need in their future jobs. Interpersonal communication, teamwork, group problem-solving, leadership, negotiation and time management are examples of these competences. In addition, positive effects have been shown in students’ academic performance, in motivation and their attitudes towards learning. Some of these advantages have also been underlined by students, who consider group activities and active methodologies to be more interesting and entertaining than traditional teaching.

Nevertheless, recent works seem to indicate that the impact of innovative initiatives on teaching practice may be limited by different factors. Sheard and Carbone (2007) observe that a significant factor is the institutional environment. Tutty et al. (2008) conclude that current institutional policies, including teaching and learning quality measures and lack of resources, are compromising the way subjects are delivered. Berglund et al. (2009) argue that teacher attitude and difficulty in the nature of the subject may also limit the range of pedagogical responses. By means of a survey, Chinn et al. (2010) identify factors that...
influenced student study habits and how those factors affected students' final course score. We have also identified certain difficulties derived from the new educational models. The significant increase of the students' workload affects the academic results achieved by certain students. They are unable to meet the deadlines when dealing with a big amount of different activities (mid-terms tests, written reports, oral presentations, etc.). Thus, a correct measurement of the real workload associated to every task and a coordination among lecturers of the different subjects turn out to be a major issue in the success of the put-into-practice of active learning methodologies. In this research work we confirm the previous assumption by gauging the opinion of the students involved in a change of methodological system that affects a global academic program.

A particular and problematic case: part-time students

Particular attention should be paid to the case of part-time students, who represent an increasing percentage of our students. The number of students enrolled in the Spanish universities has suffered a dramatic reduction in the last decade. Particularly, the number of people studying at the University of Zaragoza has fallen from the 45,291 students enrolled during the academic year 1997/1998 to the 31,566 during the 2009/2010 year. Every faculty has been affected by this important reduction, regardless the field of knowledge. Needless to say that the University authorities are very concerned about this problem and have been encouraging faculties’ deans to promote their studies and to broaden the profile of potential students towards part-time students. Professionals interested in lifelong learning turn out to be the ideal target for the student recruitment campaign of the universities. According to the point of view of the part-time students, there is mismatch between the workload required to follow a course and the offered resources, since the educational material does not take into account their particular situation. Difficulties arise when these students cannot attend the majority of the lectures, seminars and laboratory sessions and, consequently, the work planned for every week cannot be carried out. Therefore, an alternative should be given to these part-time students to facilitate their work minimizing the impact of their absence in some lecture or lab session. ANECA (National Agency for Evaluation, Quality and Accreditation, created by the Spanish Government the 19th of July of 2002) is the auditor institution of the European Higher Education Area Spain. ANECA requires Spanish universities to include in their new academic proposals developed in the post-Bologna scenario the explanation of the resources offered to part-time students to help them finish their degrees in a reasonable period. In this sense, ANECA promotes the use e-learning activities through virtual platforms (Ramos and Palacios, 2010). Nevertheless, according to answers to questionnaires and the students’ opinion expressed by other means, there is still plenty of room for improvement in this area.

Data from the students’ self-assessment process

At the end of an academic semester, the students enrolled in every course taught at the University of Zaragoza are requested to fill a questionnaire. The results of this self-assessment process fulfilled by students throughout four consecutive academic years are shown here. This survey consists of 32 likert questions where students express how
strongly they agree or disagree with a particular statement. Questions 1-18 from the questionnaire are focused on the assessment of the lecturer work. Questions 19-25 of the survey are aimed at assessing their attitude as a student. Finally, questions 26 to 32 are aimed at looking into the evaluation activities. Here, our interest is focused on the second group of questions (19-25), which are detailed below:

19. I assist regularly to lectures and laboratory sessions.
20. I consider that my previous knowledge is enough to follow the course.
21. I work daily at home on the material revised during the classes.
22. I solve any doubt/question by asking during classes or in tutorial sessions at the lecturer’s office.
23. I am satisfied with the learned concepts.
24. I think that this subject is important for my development as an engineer.
25. I consider that I am ready to pass the exams/proofs.

We have been dealing with data from students enrolled in different subjects of 2nd and 3rd year of the telecommunications engineering degree. The subjects that we have considered are listed in Table 1:

Table 1: Subjects considered during the complete period under study (2006-2010)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Semester</th>
<th>Compulsory / non-compulsory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Electronics</td>
<td>3rd and 4th semesters (2nd year)</td>
<td>Compulsory</td>
</tr>
<tr>
<td>Signals and Systems</td>
<td>3rd semester (2nd year)</td>
<td>Compulsory</td>
</tr>
<tr>
<td>Transmission Media</td>
<td>5th semester (3rd year)</td>
<td>Compulsory</td>
</tr>
<tr>
<td>Radio Communications</td>
<td>6th semester (3rd year)</td>
<td>Non-compulsory</td>
</tr>
</tbody>
</table>

Hence, we count on data of the four listed subjects from the academic year 2006/07 to the academic year 2009/10. Having data from every course, we can evaluate trends in the students' behaviour throughout time. Apart from these data, we have also considered results from two more subjects: Digital Communications (5th semester, non-compulsory) and Electronic Devices (4th semester, noncompulsory). Since we have not been responsible for these two subjects every year (other colleagues of the Department taught the course), we do not show partial results, but the comparison of sampled data from surveys of Digital Communications and Electronic Devices confirms the main conclusions.

The averaged results obtained from surveys are shown in Tables 2-5 according to the following key: (1) Strong disagree, (2) Disagree, (3) Neutral, (4) Agree, (5) Strong agree. Grey columns indicate that the project of global implantation of active methodologies was already implemented into the subject.

**Design and implementation of learning techniques at the E.U.P.T.**

One of the major educational challenges in which the E.U.P.T. has been involved is the project of design and implementation of innovative learning techniques in the context of
the 3-year degree in telecommunications engineering offered at the faculty. The progressive introduction of the active learning model was scheduled between the academic years 2005/06 and 2008/09 as shown in Table 6.
### Table 2: Results from the subject: Analog Electronics

<table>
<thead>
<tr>
<th>Statement</th>
<th>2006/07</th>
<th>2007/08</th>
<th>2008/09</th>
<th>2009/10</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 – I assist regularly to lectures and laboratory sessions.</td>
<td>4.6</td>
<td>4.2</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>20 – I consider that my previous knowledge is enough to follow the course.</td>
<td>3.7</td>
<td>4</td>
<td>3.8</td>
<td>3.1</td>
</tr>
<tr>
<td>21 – I work daily at home on the material revised during the classes.</td>
<td>2.9</td>
<td>3.8</td>
<td>3.6</td>
<td>2.7</td>
</tr>
<tr>
<td>22 – I solve any doubt/question by asking during the class or in tutorial sessions.</td>
<td>3.8</td>
<td>3.4</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>23 – I feel satisfied with the learned concepts.</td>
<td>3.6</td>
<td>3.6</td>
<td>4.1</td>
<td>3.5</td>
</tr>
<tr>
<td>24 – I think that this subject is important for my development as an engineer.</td>
<td>4</td>
<td>4</td>
<td>3.9</td>
<td>3.8</td>
</tr>
<tr>
<td>25 – I consider that I am ready to pass the exams/proofs.</td>
<td>3.9</td>
<td>3.0</td>
<td>2.9</td>
<td>2.9</td>
</tr>
</tbody>
</table>

### Table 3: Results from the subject: Signals and Systems

<table>
<thead>
<tr>
<th>Statement</th>
<th>2006/07</th>
<th>2007/08</th>
<th>2008/09</th>
<th>2009/10</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 – I assist regularly to lectures and laboratory sessions.</td>
<td>4.5</td>
<td>3.9</td>
<td>4</td>
<td>3.8</td>
</tr>
<tr>
<td>20 – I consider that my previous knowledge is enough to follow the course.</td>
<td>3.8</td>
<td>3.8</td>
<td>4</td>
<td>3.6</td>
</tr>
<tr>
<td>21 – I work daily at home on the material revised during the classes.</td>
<td>3.5</td>
<td>3.3</td>
<td>3.6</td>
<td>2.9</td>
</tr>
<tr>
<td>22 – I solve any doubt/question by asking during the class or in tutorial sessions.</td>
<td>3.7</td>
<td>3</td>
<td>3.7</td>
<td>3.6</td>
</tr>
<tr>
<td>23 – I feel satisfied with the learned concepts.</td>
<td>4.2</td>
<td>3.5</td>
<td>3.7</td>
<td>4</td>
</tr>
<tr>
<td>24 – I think that this subject is important for my development as an engineer.</td>
<td>4.3</td>
<td>3.8</td>
<td>3.7</td>
<td>4</td>
</tr>
<tr>
<td>25 – I consider that I am ready to pass the exams/proofs.</td>
<td>4.4</td>
<td>3.6</td>
<td>3.4</td>
<td>3.2</td>
</tr>
</tbody>
</table>

### Table 4: Results from the subject: Transmission Media

<table>
<thead>
<tr>
<th>Statement</th>
<th>2006/07</th>
<th>2007/08</th>
<th>2008/09</th>
<th>2009/10</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 – I assist regularly to lectures and laboratory sessions.</td>
<td>4.8</td>
<td>4.7</td>
<td>4.5</td>
<td>4.2</td>
</tr>
<tr>
<td>20 – I consider that my previous knowledge is enough to follow the course.</td>
<td>3.9</td>
<td>4</td>
<td>3.6</td>
<td>3.7</td>
</tr>
<tr>
<td>21 – I work daily at home on the material revised during the classes.</td>
<td>3.4</td>
<td>3.6</td>
<td>3.3</td>
<td>3.2</td>
</tr>
<tr>
<td>22 – I solve any doubt/question by asking during the class or in tutorial sessions.</td>
<td>3.7</td>
<td>3.8</td>
<td>3.5</td>
<td>3.8</td>
</tr>
<tr>
<td>23 – I feel satisfied with the learned concepts.</td>
<td>3.9</td>
<td>4.3</td>
<td>4</td>
<td>3.6</td>
</tr>
<tr>
<td>24 – I think that this subject is important for my development as an engineer.</td>
<td>3.9</td>
<td>4.3</td>
<td>4.2</td>
<td>3.7</td>
</tr>
<tr>
<td>25 – I consider that I am ready to pass the exams/proofs.</td>
<td>4.1</td>
<td>3.7</td>
<td>4</td>
<td>3.6</td>
</tr>
</tbody>
</table>

### Table 5: Results from the subject: Radio Communications
The curriculum of the telecommunications engineering degree, focused on electronic systems, was designed to promote the students’ ability to detect, analyze and solve technological problems using decision-making tools and problem-solving processes.

The process of design innovative learning activities to be included into the academic program started with the analysis of the required professional profile as well as the generic and specific competences that must be acquired by the students throughout their stay at the faculty. The proposed learning activities designed to fulfill the requirements were included in the new teaching guides. The project finished with a process of internal and external assessment carried out so as to evaluate the accomplishment of the initial objectives.

**Conclusions and recommendations**

Significant differences appear between the results obtained from the compulsory and the non-compulsory subjects. This fact can be explained if we considered the way in which lecturers have been working in the non-compulsory subjects under their responsibility well before the project of the global introduction of innovative techniques into the program started. Then, in the context of the vast majority of the non-compulsory subjects offered at the E.U.P.T., active methods of learning have been used by lecturers on their own initiative for more than 10 years (Ramos and Palacios, 2010). The reduced number of students per class allowed lecturers to put into practice innovative methodologies and the positive feedback obtained from the students encouraged lecturers to keep working in these topics. Although each lecturer has been taking a different approach to the active methods, the proposed activities shared a common framework and the students expect innovative activities during the lectures and the laboratory sessions when they enrolled in the course. Thus, the global implantation of the innovative system had no effect in the non-compulsory subjects since it simply consisted in a coordination task. This statement is confirmed by results listed in Table 5, since answers to every question are very similar.
regardless if they are taken before or after the project reached the academic year in which the subject is taught.

Hence, according to the results obtained from the questionnaires (which confirm other positive feedbacks) we can conclude that in the non-compulsory courses, students show a steadily positive behavior during the period of time covered by this research: they have a high degree of motivation and a very positive attitude towards these subjects. Therefore, they follow the course without difficulties, they enjoy attending lectures and lab sessions, they work regularly at home and, consequently, they expect to pass successfully the tests and exams in the upcoming weeks (Table 5).

Nevertheless, as far as the compulsory courses are concerned, a trend in the pattern behavior of the students has been observed. With the advent of the student-oriented educational paradigm, a carefully planned time schedule and daily work at home turn out to be a must in order to obtain a successful evaluation. A certain percentage of students used to put special emphasis on their work during the month previous to the final exams. This “last-minute” strategy can (sometimes) be effective if the evaluation process consists uniquely in a written exam but, when the number of midterm tests, oral presentations and other activities increases and spreads throughout the semester, these students cannot deal with the new scenario. According to the answers to question 19 shown in Tables 2, 3 and 4, with the new methodological system they fail to attend lectures more often than in the traditional scenario. This fact is due, partly, to the lack of time. Since students realize that they are going to be unable to meet every deadline, they show a sense of pessimism, as it is reflected in their answers to the questionnaires, where an increasing number of students recognize a deficient organization and a lack of engagement with the daily work. Unfortunately, these students, aware of their slim chances to pass the tests and to meet the deadlines (see answers to question 25 in Tables 2 and 3), are prone to give up.

In order to improve the academic results obtained by students enrolled in the compulsory subjects we encourage lecturers responsible for these courses to create in class the positive work atmosphere that one may found typically in a non-compulsory course. Besides, universities could transitorily propose two alternative evaluation systems for a course. Students could choose the system that better suits their particular situation: then, students engaged with the progressive system of learning would be evaluated on the basis of tests and reports spread during the semester whereas students that can no deal with this exigent schedule could opt for a final exam.

To sum up, we would like to emphasize the importance of the correct measurement of the workload associated to every task proposed in the context of a course. A subject makes sense in the context of an academic course and not as an isolated item. We consider that the role played by the degree’s coordinator is of capital importance. She/he should distribute correctly the different activities and deadlines throughout the semester with a panoramic perspective that a particular lecturer frequently underrates. Otherwise, the promising change in the learning paradigm that aims at improving the teaching-learning process can affect negatively to the students performance, particularly to those parttime students who have a more limited time to attend lectures and work at home. Here, we would like to enhance the importance of the ANECA requirement of including the
explanation of the resources offered to part-time students in the new academic programs. Taking into account their comments and suggestions we are not yet considering conveniently their particular – and very frequent in nowadays universities– case.

References


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Design of Competences-based Educational Programs for engineering education
understanding curriculum as a process

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Abstract: The research has focused on the design of the curriculum of an engineering degree, taking into account the development and assessment of generic competences. To accomplish that, we have conceived the curriculum as a process approach, which facilitates the identification of elements, their interactions and their expected performances. The goal we expected to reach deals with the creation of a system perfectly tuned having inputs, outputs and feedbacks which let us improve student performance in competences acquisition, optimizing at the same time efforts in every element of the global process of teaching and learning.

Introduction

This paper deals with the design of a degree in computer engineering from the point of view of the European Space for Higher Education (in the sequel, ESHE). The process of adaptation to the ESHE brings with itself a new understanding of both teaching and learning procedures. The vertiginous technological advance of our society entails continuous learning and this is generating a necessity of using educational models that allow the students to "learn to learn". It entails continuous learning and this is generating a necessity of using new educational models based on a constructivist approach conveying an important change from traditional methods to education based on cognitive theory.

In this sense, the Spanish Organic Law of Universities (2001) in its first article establishes "The creation, development, transmission and criticism of Science, Technology and Culture" as the first function of a University. Consequently, students must develop intellectual, technical, artistic, social and personal abilities. These abilities or competences will encourage creativity, problem solving and autonomous learning through all their life. Competences represent a dynamic combination of knowledge, understanding, skills and abilities.
As far as competences acquisition/development assessment, there are a lot of different points of view, discussing the most suitable measuring ways to assess the student deal of competence acquisition. In tune with the aforementioned ideas, the focus on processes is also useful to design assessment systems based on competences acquisition. We have developed a guide for both lecturers and students in order to accomplish an assessment as much objective as possible. Every single generic competence is divided in different levels of achievement. Basically, this includes a clear and explicit definition about the requirements that should be fulfilled for every single numerical associate value. The level of development for the student will be represented by a numerical mark, which will be decided in agreement with a pre-established criterion of valuation.

The paper is presented as follows: section 2 introduces the curriculum as a process with the necessary inputs, outputs as well as the continuous improvement basis. Section 3 deals with generic competences in computer engineering, showing the ones selected in our study together with the valuation scales to measure the development of every single competence. Section 4 presents some results obtained and section 5 presents the main conclusions together with future work.

The curriculum as a process

We can define the curriculum as an effort joint and planned, destined to lead the student learning towards a few before established results. Thus, all the elements taking part in the educational process are inter-related to achieve the demanded professional and occupational profiles. From this idea, the research has focused on the design of the curriculum of an engineering degree, taking into account the development and assessment of generic competences. To accomplish that, we have conceived the curriculum as a process means to identify first a system composed by interrelated elements, with a clear common aim and a border that separates it what it is possible to identify as "context". Thus, the above mentioned system receives a few inputs, performs certain activities and returns to the context a few outputs as result of the development of the above mentioned activities with an added visible and measurable value, as well as also some losses. The elements of a process (according to the ISO 9000:2000 regulation) are the following: inputs, outputs, resources, procedures, client, indicators and owner. The process approach facilitates the identification of elements, their interactions and their expected performances.

Inputs to the system

The source of inputs to the system has two origins: on one hand, the institutional context of the University of Zaragoza, and on the other hand, the socio-economic context in which the university is inserted. The input from the University includes, among other aspects, the institutional directives on curricular aspects and its orientations. In the same way, they are incorporated that learning of previous years that were useful. As far as the socio-economic context is concerned, it brings itself useful information via general regulations at a Ministry of Education level, the Spanish National Agency for Quality Assessment and
Accreditation (in the sequel ANECA) or different surveys carried out with international experts related to multinational teaching environments (Fernandez et al., 2011), etc.

**Outputs of the system**

The principal output of this system remains demonstrated by the impact of the graduates in the society, fact that it is possible to see from two points of view. The first one bears in mind what profile the graduate has developed in his/her training as Computer Engineer according to the professional profile established in the program, whereas the second one projects more towards what the graduate does in his/her job, that has also remained defined in the corresponding occupational profile.

These outputs are gathered by means of a few indicators. They gather information from a particular job environment and from professional associations in general, which offer useful information to do the analysis "plan vs. real" from the head of the program. The same operating way becomes evident in feedbacks of employers and of graduates.

As a result, corrective actions can arise in order that the gap between that really perceived by graduates and the planned from the formative process of the program (professional and occupational profiles, respectively) goes towards harmony. This tries to tune dynamically both profiles to accomplish two goals at least: the first one, an appropriate adaptation to his/her socioeconomic context being transformation agents of society (relevancy competences), and the second one, the integral education university gives them as people (identity competences). There must be a feedback in the formative process taking into account the most significant findings in the profiles evaluation and validation process.

**Management and continuous improvement in curriculum**

To consolidate the continuous improvement process, the authors propose to follow the "continuous improvement spiral" (also known as the "Sheward cycle" or "PDCA cycle"). This model consists of a logical sequence of four repetitive steps for continuous improvement: P (Plan), D (Do), C (Check), and A (Action). The experience of the organizations has showed that is possible to manage any type of process efficiently like this. This kind of feedback mechanism has been previously used in engineering education (Plaza et al., 2006). The study has been carried out taking into account the degree of Computing Engineering, but it can be easily extrapolated to other engineering degrees.

According to the elements described above, the curriculum of the program from the processes approach allows us to rely on an information and feedback system especially useful in the involved taking-decision processes. In particular, it tries to facilitate the decisions related to: a) students entering the program and their profiles, b) graduates of the program and their profiles, c) measures of the performance of the formative process and its continuous improvement. For each of them, this approach allows to carry out solidly at least the following functions, typical from the curricular management: to identify the period of achievements of results, to identify the corrective and preventive actions as well as to have a feedback channel.
Generic Competences in Computer Engineering

The Tuning project (Tuning, 2008) proposes a total of 30 generic competences classified in three groups: instrumental, interpersonal and systemic. Although it acknowledges the full importance of building-up and developing subject specific knowledge and skills as the basis for university degree programmes, it has highlighted the fact that time and attention should also be devoted to the development of generic competences or transferable skills. We describe the main objectives of them:

**Instrumental competences:** having an instrumental function, the main objective of these competences is to provide students with means and methods allowing them to use put knowledge in practice in the work environment.

**Systemic competences:** engineers should have the ability to understand the social and economic context belonging to the sector in which they develop theirs activities. For this reason, it is necessary for them to show an enterprising attitude to find possibilities and to define objectives, together with the managing and teamwork abilities.

**Interpersonal competences:** as the engineer work will be developed into workgroups, abilities to communicate and teamwork are fundamental in the success, increasing possibilities of promotion. Solutions should be not only technically adequate but understandable.

There is a group of generic competences that have been established by an expert committee in charge of the elaboration of the educational program. Several studies carried out previously by different institutions such as ANECA (through the Computing Engineering Guide) together with several reports coming from professional associations, qualified people and lecturers have been considered. In order to gain a deeper understanding of which generic competences or 'soft skills' are the most important ones to help students and professionals, we have also taken into account the survey carried out in (Fernandez et al., 2011) with international experts related to multinational teaching environments.

<table>
<thead>
<tr>
<th>Instrumental</th>
<th>Interpersonal</th>
<th>Systemic</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC-1: Aptitude to conceive, to design and develop projects in the field of Engineering.</td>
<td>GC-5: Aptitude to communicate and transmit knowledge and skills in Spanish.</td>
<td>GC-3: Aptitude to combine both general and specialized knowledge in Engineering to generate innovative and competitive proposals in the professional activity.</td>
</tr>
<tr>
<td>GC-2: Aptitude to plan, to budget for, to organize, to direct and control tasks, people and resources.</td>
<td>GC-8: Aptitude to be employed at a multidisciplinary group and at a multilingual environment.</td>
<td>GC-4: Aptitude to solve problems and to take decisions with initiative, creativity and critical reasoning.</td>
</tr>
<tr>
<td>GC-9: Capacity of management of the information, managing and application of the technical specifications and the legislation necessary for the practice of the Engineering.</td>
<td></td>
<td>GC-7: Aptitude to analyze and value the social and environmental impact of the technical solutions acting with ethics, professional responsibility and social commitment, looking always for the quality and the continuous improvement.</td>
</tr>
<tr>
<td>GC-11: Aptitude to apply the technologies of the information and the communications (ICTs) in the engineering field.</td>
<td></td>
<td>GC-10: Aptitude to learn in a continuous way and to develop strategies of autonomous learning.</td>
</tr>
</tbody>
</table>

Table 1: Generic Competences (GC) considered.
Valuation scales in competences development

Regarding the ways of measuring the development reached in a competence in particular, there are many points of view about which of them are more suitable (Tobón, 2006). Some institutions have applied a scheme of valuation from a set of criteria or requirements associated with every numerical value that might be obtained in every case. Basically, this includes a clear and explicit definition about what requirements must be fulfilled for every numerical associate value.

This scale of valuation will be the used along the whole subject, and the lecturer must put the level of achievement that is supposed to be reached by the student for that subject. As an example, the following tables show the different levels of achievement in the development that can be reached in every single generic competence, within the different subjects of the degree.

Table 2: Example of criteria definition and valuation scale for the competence GC-4 and the subject ‘Software Engineering’

<table>
<thead>
<tr>
<th>Year 3 (1st term)</th>
<th>Subject Example: Software Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competence</td>
<td>Description</td>
</tr>
<tr>
<td>CG-4. Aptitude to solve problems and to take decisions with initiative, creativity and critical reasoning. (Resolution of Problems and Decision-taking)</td>
<td>He or she takes risks and adopts the decision that considers being more opportune without a previous evaluation.</td>
</tr>
<tr>
<td></td>
<td>He or she collects information to be able to elaborate a wiser diagnosis and takes a decision.</td>
</tr>
<tr>
<td></td>
<td>He or she understands the nature of the problem, the involved restrictions.</td>
</tr>
<tr>
<td></td>
<td>He or she identifies alternatives, evaluates them and determines their involvements, determining priorities according to the aim of the decision to be taken</td>
</tr>
<tr>
<td></td>
<td>He or she takes the decision that considers being more opportune in terms of cost/efficiency.</td>
</tr>
</tbody>
</table>

Results

Once the competences were outlined, every lecturer determined the subject objectives and related them to both generic and specific competences. They established the different levels of achievement taking into account the importance and the deal of development during the course. The present study deals only with generic ones. The survey has been fulfilled by all the academic staff belonging to the degree of Computing Engineering. Lecturers have established the level of achievement for those competences to be developed in every single subject. Nearly thirty lecturers have participated in the survey.
According to figures 1 and 2, we can point out that according to lecturers’ point of view, the most valuable competence is GC-4, which should be developed in nearly 90% of the subjects belonging to the degree as well as from 1st year subjects on. Generic competences GC-11 and GC-10 should also be developed in more than 50% of subjects. GC-9 is only developed in 4th year, whereas GC-6 competence is most developed in 2nd year (55% of subjects). Competences GC-2, GC-3, GC-7, GC-8 and GC-9 are developed from 2nd year on, which is totally reasonable because these competences are supposed to need more experience in the engineering field to be developed in a suitable way.

As far as the level of achievement to be reached in each competence is concerned, we must remark that common sense tells that this level should be increased as the degree moves forward, that is to say, it is desirable that in first year subjects this level is no more than level 2. In the same way, last years subjects should develop the top level of competence achievement. The following figure shows the evolution of the level of achievement for competence GC-4 along the years and subjects.

In figure 3, we see that competence GC-4 is developed homogeneously all along all the four years, whereas competence GC-3 is developed fundamentally in third and fourth years. Concerning GC-3, it is developed along levels, for example, levels 1 and 2 will be those that the student should reach in first and second year. Those subjects which develop it (8.70% of the total) will have to relate specific knowledge of the specific competences to the analysis and synthesis of acquired knowledge, which allow them to identify problems and to use this acquired knowledge to solve problems. The development of this competence in 3rd and 4th years will reach levels 3, 4 and 5. GC-4 has a similar behaviour because the subjects developing this competence will work the 3 levels of development, but with a gradual increase in the difficulty of the problems. Levels 4 and 5 will be necessary in last years; nevertheless, lecturers will have to introduce the concepts in previous subjects to make students aware of the importance of both efficiency and cost analysis in the development of software.
Conclusions

The introduction of competences on the curriculum will have positive effects in students’ academic performance, in motivation and their attitudes towards learning. In this work we expect to find the best curriculum design as far as development of generic competences is concerned. Thinking in curriculum as a global process, we have taken into account a series of inputs, such as institutional directives, socio-economic context, competences demanded by companies, ANECA recommendations as well as several surveys related to multinational environments. We hope that our outputs will tune as the implementation goes on in order to get the right balance. This work constitutes only a preliminary study which should be tuned according the feedbacks received. As the courses move forward, we will be able to valuate if the competence development is suitable or not. So, it is clear from it that an indepth analysis of the outcomes should be carried out on a yearly basis, in order to correct possible mismatches. At the end, and taking into account the degree as a whole, we must be able to put the correct weights in both competences to be developed and the level of desired achievement in every single course/subject, respectively. This task will optimize efforts in both agents of the system (students and lecturers).

Future work deals with the assessment system of competences understanding it also as a process, in order to valuate how the formative process has contributed to the harmonic development of the established competences. They will play an important role in both the professional and the occupational profiles of graduates. According to what we have dealt with in previous sections, we think that the process approach will be useful when designing an assessment system. The final goal deals with having a coherent instrument to measure the development of competences.

Once more, the introduction of the concept of process means that evaluation is a system in which inputs (examinations and assessment criteria, lecturers, students, etc) turn into to allow decision-taking about the student performance improvement. The PDCA cycle will let us correct the possible imbalances and work on their improvement. In such a way, we...
will be able to answer the following questions, among others: how is knowledge integrated with skills, attitudes and values? Which aspects are necessary to improve? Which is the level of achievement in performance? How is activity being done?

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Educational Experience of Adaptation of a degree in Electronic Engineering from the ECTS standpoint within the European Higher Education Area Framework

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Abstract: The present paper discusses results of the global study carried out during the past four years to estimate the student workload (an ECTS preliminary estimate) for the whole degree of Electrical and Electronic Engineering. At the same time, the different methodologies advocated by the European Space for Higher Education have been put into practice in order to promote the acquisition of both specific and generic competences and skills belonging to the degree. On this paper we also analyse the development of student’s generic competences along these four years.

Introduction

The general directives to adapt educational systems to the European Space for Higher Education (ESHE) set up in the Bologna declaration (1999), are related to competitiveness of the European Higher Education Area (EHEA), to students and lecturers’ mobility as well as to the incorporation of students in the industrial and business world. Everything will cause deep changes. We believe that the main change will take place in the introduction and development of student’s generic competences.

So far, what students acquired in a few years was supposed to be enough for the rest of their professional lives. The vertiginous technological advance of our society entails continuous learning and this is generating a necessity of using educational models that allow the students to "learn to learn". From the student’s point of view these educational models are more active. The gradual adaptation of the subjects will allow lecturers to act carefully and thoughtfully when facing the necessary adaptation to the new educational framework.

The present paper shows the global study fulfilled during the past four years to analyse the incorporation of both competences to the Electrical and Electronic Engineering degree curriculum as well as to measure the workload student along this process. The experience
has been carried out at Teruel Polytechnic School of Engineering, belonging to the University of Zaragoza (Spain). It began in academic year 2006/2007 with the design of the first course of the Electrical and Electronic Engineering degree from the ECTS standpoint. In academic year 2007/08 the study was put into practice for the 1st year students. The following years the same operating way was developed and applied for the second and third years of the degree, respectively. Results obtained will let us correct not only the curriculum established but also the tested methodological strategies to develop student’s competences and to work on their improvement.

The paper is presented as follows. Section 2 presents the previous and preliminary theoretical analysis of both curriculum and competences to be acquired by students in the whole degree. Section 3 deals with the introduction of objectives, methodologies and planned activities. Section 4 puts in practice the theoretical study, showing a comparative analysis between both theoretical and practical student workload and the student’s competences development. Finally, section 5 presents the main conclusions.

Preliminary Analysis of Curriculum and Competences

Along the course year 2006/07, lecturers in charge of the subjects of the first year of the degree set up a workgroup to analyse the curriculum, subject's credit as well as the competences and skills to be acquired by students. They worked on both individual and group basis. In the framework of ESHE the credits meaning changes. ECTS credits measure all the academic work carried out by one student to reach the objectives. Therefore, these credits include activities such as class attendance, both theoretical and practical, lessons preparation, individual study, tests and exams, guided projects, seminars and tutorials. One ECTS credit should be between 25 and 30 hours of student’s work; moreover, experience will show us that the value of a credit in engineering degrees usually is closer to the second value.

One of the first goals of the project was the design of a new educational guide according to ESHE. To prepare the guide the following tasks were developed: Description and contextualization, analysis of competences, definition of the objectives of each subject, selection and organization of the contents, teaching methodology and work plan and assessment. Next two years the curriculum of second and third course was carried out on the same way by the teachers in charge of these subjects.

The Spanish Organic Law of Universities (2001) in its first article establishes "The creation, development, transmission and criticism of Science, Technology and Culture" as the first function of a University. Consequently, students must develop intellectual, technical, artistic, social and personal abilities. These abilities or competences will encourage creativity, problem solving and autonomous learning through all their life.

The Tuning project proposes a total of 30 competences classified in three groups: instrumental, interpersonal and systemic. To carry out the present teaching guide we considered the generic competences that were specified in the Electrical and Electronic Engineering guide proposed by the Spanish National Agency for Evaluation and Accreditation (ANECA), where the importance of each of them was valued starting from
the results analysis of surveys carried out to company communities, qualified people and lecturers.

We selected from that guide the main competences that our students had to develop and we used them as the starting point to design our subjects. Along all study, surveys were carried out to measure the development of these competences on the following courses, as well as to estimate the importance students though they had. We studied also the specific competences. However, we do not deal with this topic on this paper.

Competences represent a dynamic combination of knowledge, understanding, skills and abilities. Although the Tuning Project acknowledges to the full the importance of building-up and developing subject specific knowledge and skills as the basis for university degree programmes, it has highlighted the fact that time and attention should also be devoted to the development of generic competences or transferable skills. This last component is becoming more and more relevant for preparing students well for their future role in society in terms of employability and citizenship. Briefly, we remark the main características of every single type of competence:

**Instrumental competences:** Having an instrumental function, the main objective of these competences is to provide students with means and methods allowing them to put knowledge into practice in the work environment.

**Interpersonal competences:** as an engineer work will be developed into workgroups, abilities to communicate and teamwork are fundamental in the success, increasing possibilities of promotion. Solutions should be not only technically adequate but understandable.

**Systemic competences:** Electrical and Electronic engineers should have the ability to understand the social and economic context belonging to the sector in which they develop theirs activities. For this reason, it is necessary for them to show an enterprising attitude to find possibilities and to define objectives, together with the managing and teamwork abilities.

<table>
<thead>
<tr>
<th>Instrumental</th>
<th>GC-1. Capacity for understanding and interpreting written information in a critical way.</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>GC-2. Capacity for organization and planning.</td>
</tr>
<tr>
<td></td>
<td>GC-3. Oral communication in your native language.</td>
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<tr>
<td></td>
<td>GC-4. Ability to communicate ideas in different contexts.</td>
</tr>
<tr>
<td></td>
<td>GC-5. Capacity for understanding and interpreting written information in a second language.</td>
</tr>
<tr>
<td></td>
<td>GC-6. Written communication in your native language.</td>
</tr>
<tr>
<td></td>
<td>GC-8. Elementary computing skills.</td>
</tr>
<tr>
<td></td>
<td>GC-9. Information management skills (ability to retrieve and analyse information from different sources)</td>
</tr>
<tr>
<td></td>
<td>GC-10. Capacity for analysis and synthesis.</td>
</tr>
</tbody>
</table>

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Interpersonal
GC-13. Ability to work in a team with responsibility and flexibility (teamwork).
GC-17. Appreciation of diversity and multiculturality.
GC-18. Ethical commitment.

Systemic
GC-20. Ability to work autonomously.
GC-21. Capacity to adapt to new situations.
GC-24. Understanding of cultures and customs of other countries.
GC-27. Sensibility to environmental matters.

Table 1 shows the competences taking into account in our study.

Objectives, contents, methodology and assessment

Once the competences were outlined, each lecturer determined the subject objectives and related them to both generic and specific competences. Afterwards, they detailed contents and teaching activities. The activities outlined were selected from Alfaro (2006), where they were classified into big group work, seminars, practical classes, ECTS tutorials, autonomous work in groups and individual autonomous work. We expected that the educational model would not be centred exclusively on lectures but rather it would promote different types of work such as group work, individual study and tutorials.

As a result of the activities designed, lecturers estimated the number of hours that every single student would have to work to pass each subject. Finally, once the planning and the sequence of activities were designed, lecturers established the subject assessment criteria. All the obtained data were collected and a new guide was generated.

Activities Planning

According to the Bologna process and university general directives, one student is supposed to work about 40 hours per week during the academic year to be in the best conditions to succeed. Therefore, the distribution of activities was planned in such a way that students should devote forty hours per week, approximately, taking into account both work at classroom and autonomous work.

The first year usually begins with a greater load of activities at classroom especially lectures and problem sessions, because students do not have the necessary knowledge to develop more interactive activities. For that, it is highly recommended to give them a theoretical basis that let them develop the skills and required attitudes. As fast as the student acquires the basic knowledge, interactive activities will be introduced step by step (seminars, practical lessons, etc.). These activities will let students have a higher level of autonomy. In accordance with the planning of second and third years, there will be more students’ autonomous work and less work at classroom. From the beginning of each course, students have the detailed planning, being conscious about the follow-up necessity.
Practical Experience

During the academic year 2007/08 we started the implementation of the study developed the year before. Along three years, a great number of data was collected from both students and lecturers, to compare both theoretical analysis and practical implementation. Student work dedication was gathered via internet, by means of a web application in which students were introducing workload data on a weekly basis.

Student’s work dedication

Figure 1 and Figure 2 show that the planned student’s workload on the three courses are around 40 hours, however, on first and second years students works below it. In general, students devoted fewer hours on average than they should dedicate to the study and preparation of all subjects (including personal work and work at classroom). On third year, students had to perform a final project with a medium-high complexity, taking into account all the acquired knowledge and using it in a joint way. It will increase the workload. The real autonomous work was around 13.5 hours per week on average the first year, 17 hours the second year and 26 hours the third year. In general, we can affirm that along the three years, students have improved their capacity of autonomous work. Autonomy will be really useful for our students to get a good insertion into labour market.

![Figure 1: 1st Term Student's Workload per Week (Hours). Planned vs. Real.](image1)

![Figure 2: 2nd Term Student's Workload per Week (Hours). Planned vs. Real.](image2)

Percentages are exchanged when we compare the established figures in the planning and the real ones (Figure 2). For example on the 1st year the planning of student’s personal work was about 61.54% of the total work, and the rest, 38.46% was the percentage of work in the classroom. The real one was 46.79% of student's personal work and 53.21% of work in the classroom. The same happened on second year, 66.85% of student's personal work on second course became 56.18%. However, 63.37% became 66.02% of student’s personal work on third year, increasing the planning percentage. Student workload is very important in the planification of the whole academic year and the degree. If we do not plan carefully all the teaching and learning activities, we may incur in mismatches. In other words, the number work hours higher, the worse academic performance, because we might saturated students with an excess of work. On the other
hand, the number of hours lower, the worse competence acquisition and academic performance, respectively. In this case, we must assure that both educational programs and competences acquisition are fulfilled.

**Student opinion about competences development**

During the academic year 2008/09 we designed a survey to be completed by students belonging to the degree in Electrical and Electronic Engineering. We have centred our study on the analysis of generic competences. They survey was completed by more than three hundred students belonging to the aforementioned degree. We show in this section several comparative analyses with the collected data at the end of the second term. Marks were put from 0 to 5.

Figures 3 and 4 show competences valuation from the following points of view:

a. what students think about their importance in their education.

b. what students think the way they have been developed in the current academic year (in a greater or lesser degree).

c. what students think about their importance in the labour market.

According to figure 3, showing student valuation taking into account the point of view b), it can be observed that valuations are above 3. The competences most valued by 1st year students were Elementary computing skills (C8), Information management skills (ability to retrieve and analyse information from different sources) (C9) and Interpersonal skills (C16). The less valued were capacity for understanding and interpreting written information in a second language (C5), written communication in your native language (C6) and ability to work in an international context (C15).

![Figure 3: Competences valuation from the point of view b), what students think the way they have been developed in the current academic year. Y-axis: score (0 to 5)](image)

![Figure 4: Average of three years competences. Y-axis: score (0 to 5)](image)

Similar to 1st year, 2nd year valuations are above 3. Competences most valued were elementary computing skills (C8), problem solving (C11) and ability to work in an interdisciplinary team (C14). Less valued were knowledge of a second language (C7), ability to work in an international context (C15), ethical commitment (C18) and understanding of cultures and customs of other countries (C24). As far as 3rd year is
concerned (fig. 3), most valued competences were: capacity for analysis and synthesis (C10), problem solving (C11) and concern for quality (C26). Least valued competences were ability to work in an interdisciplinary team (C7), ability to work in an interdisciplinary team (C14) and understanding of cultures and customs of other countries (C24). According to figure 5 and 6, we observe that instrumental competences were most valued, following systemic and personal competences, respectively. However, students think (see figure 4) that they have been developed in a lesser extent (current year).

![Figure 5: Average of three points of view and three years data group by competences type (classified per competences)](image)

![Figure 6: Average of three points of view and three years data group by competences type](image)

We can see that in general the nivel of competences are being worked below of expecting (Figure 4). To sum up, according to figure 5, the more valued competences on average and taking into account the three points of view have been Problem solving (C11) and Elementary computing skills (C8).

**Conclusions**

Several sources have propounded the advantages offered by considering different methodologies in order to acquire the skills and competences students will need in their future jobs. Interpersonal communication, teamwork, group problem-solving, leadership, negotiation and time management are competences our students have to develop. The introduction of competences on the curriculum has had positive effects in students’ academic performance, in motivation and their attitudes towards learning. Some of these advantages have also been underlined by students, who consider group activities and active methodologies to be more interesting and entertaining than traditional teaching. In this work, we have dealt with the importance of competences acquisition in engineering education; in particular, we have focused our analysis on the field of Electrical and Electronic Engineering. Due to the forthcoming implementation of the new educational model focused on the student, teaching/learning activities should be carefully designed and schedule to reach the educational goals as far as competence acquisition is concerned.
Results obtained in practice will let us correct the tested methodological strategies and work on their improvement. Taking into account competences demanded by companies, we may conclude that, in general, that competences most valued by students are really interesting for the labour market, though there are some others (second language, leadership, initiative and enterprising spirit, principally) less valued but important for companies as well. In this respect, lecturers will have to emphasize their importance, trying to develop them at the classroom. On the other hand, student still dedicate less hours to autonomous work than they should. Both students and lecturers should work more to get increase the student's private work, continuous work and competences level developed.

References


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