Introducing engineering education in the middle school

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Abstract: *This paper first describes a new three-year, longitudinal project that is implementing engineering education in three middle schools in Australia (grade levels 7-9). This important domain is untapped in Australia. Hence, as a starting point, we conducted a context analysis to help situate engineering education in a school system. We report on this analysis with respect to findings from one of two literature-based surveys that gathered middle-school student responses in mathematics (n=172) and science (n=166) towards understanding their dispositions for engineering education. ANOVA indicated gender differences for 3 out of 23 items in both mathematics and science. In addition, the majority of students agreed or strongly agreed with 17 of the 23 survey items, however, there were some differences between mathematics and science. We conclude the paper with some recommendations for establishing engineering education in schools, including the development of partnerships among engineering and education faculties, school systems, and industry to develop contemporary engineering resources to support school-level mathematics, science, and technology.*

Context

In recent years, many nations have experienced a decline in the number of graduating engineers, an overall poor preparedness for engineering studies in tertiary institutions, and a lack of diverse representation in the field (Dawes & Rasmussen, 2007; Downing, 2006; Lambert, Diefes-Dux, Beck, Duncan, Oware, & Nemeth, 2007). With respect to Australia, the number of engineering graduates per million lags behind most of the other OECD countries (Taylor, 2008). Furthermore, female students are still underrepresented in engineering, which "has the distinction of being the most male dominated of all the professions" (Dhanaskar & Medhekar, 2004, p. 264). This shortage of skilled engineers is impacting significantly on the ability of companies and organizations to undertake and complete projects (*Engineers Australia*, *Technically Speaking*, 2008).

Given the increasing importance of engineering and its allied fields in shaping our lives, it is imperative that students be given opportunities to develop a drive to participate in engineering from a young age, to increase their awareness of engineering as a career path, and to be better informed of the links between engineering and the enabling subjects, mathematics and science. The middle school has been identified as a crucial period here—for either encouraging or discouraging students' participation and interest in mathematics and science, and ultimately, their interest in engineering as a profession (Brophy, Klein, Portsmore, & Rogers, 2008; Tafoya, Nguyen, Skokan, & Moskal, 2005).

Engineering education in the middle school is a significant, emerging field of research. It aims to foster students' appreciation and understanding of what engineers do, how engineering shapes the world around them, how engineering utilises important ideas from mathematics and science, and how it contextualises mathematics and science principles (Dawes & Rasmussen, 2007; English & Mousoulides, in press).

New Project, 2009-2011

An Australian Research Council Linkage grant was awarded to the authors for a three-year, longitudinal project that is implementing engineering-based experiences in the middle school (grade levels 7-9, 12 – 14 year-olds). In implementing such experiences, the project aims to:

1. Introduce students and their teachers to foundational engineering ideas, principles, and design processes, which draw upon existing mathematics and science curricula;
2. Foster students' and teachers' knowledge and understanding of engineering in society; and
3. Increase the existing knowledge base by documenting and evaluating (a) developments in students' and teachers' learning in engineering, including a focus on any student gender differences, and (b) ways in which engineering education can be implemented in the middle school curriculum.

Theoretical Framework

An understanding of design processes is fundamental to engineering, as it is to solving many complex real-world problems (Cunningham & Hester, 2007; Wood, Hjalmarson, & Williams, 2008). Applying such processes in solving engineering problems requires interdisciplinary knowledge, especially mathematics and science, and powerful problem solving and reasoning processes. Also needed here is the creation, application, and adaptation of mathematical/scientific models that that can be used to interpret, explain, and predict the behaviour of complex systems (English & Mousoulides, in press; Zawojewski, Hjalmarson, Bowman, & Lesh, 2008). The cyclic processes of modelling and design are very similar: a problem situation is interpreted; initial ideas (initial models, designs) for solving the problem are called on; a promising idea is selected and expressed in a testable form; the idea is tested and resultant information is analyzed and used to revise (or reject) the idea; the revised (or a new) idea is expressed in testable form; etc. The cyclic process is repeated until the idea (model or design) meets the constraints specified by the problem (Zawojewski et al., 2008).

Design-based problems require students to initially interpret the problem goal/s, identify important variables, and begin to define an end-in-view of the solution they are to design. The end-in-view (English & Lesh, 2003; Wood et al., 2008; Zawojewski & Lesh, 2003) refers to the students' interpretations of the qualities of the final solution they are required to design. As they work on solving the problem, student groups develop a better understanding of the problem itself, its goals, the constraints to be faced, and the criteria to be met for success. Students' end-in-view thus evolves during the course of solution as they become increasingly able to determine when they have created an effective product (Wood et al., 2008).

The engineering problems we are implementing enable students to directly experience the relevancy of their schooling to real-world problems, as well as experience a direct link between their education, their community, and themselves. Rather than presenting students with facts and procedures, the problems are designed to engage students in personal construction of new knowledge, promote disciplined inquiry, and help students see the value of the learned material beyond the classroom (Dawes & Rasmussen, 2007). Results from a design-based approach compared to a scripted inquiry approach in middle school science found that the design-based approach had superior performance in terms of knowledge gain achievements in core science concepts, engagement, and retention when compared to a scripted inquiry approach (Mehalik, Doppelt, & Schuun, 2008).

Methodology

Participants

Middle school classes (grade levels 7-9) and their teachers from three Queensland (Australia) schools (two single-sex and one co-educational) are participating in the project (year 7 in 2009, year 8 in 2010, year 9 in 2011). In addition, given that one of the major difficulties in inspiring school students to consider engineering as a career is their lack of knowledge and understanding of the domain (Dawes & Rasmussen, 2007, Hirsch, Carpinelli, Kimmel, Rockland & Bloom, 2007, Richards, Laufer, & Humphrey, 2002), the project includes participation by final-year undergraduate engineering students and mathematics and science teacher education students from the Queensland University of Technology. The Queensland Department of Main Roads is also an important industry partner; they will contribute by providing access for the schools to young engineers and showcase interesting and best practice projects relating to the engineering activities developed.

Engineering foundations

The engineering experiences we are implementing complement and build on existing core science and mathematics curricula. In contrast to the usual tasks students encounter in class, our engineering activities allow multiple solutions of varying sophistication and cater for students with a range of personal backgrounds and knowledge (Byers & Dawes, 2007). The activities are designed to develop powerful knowledge and understandings of engineering, together with skills and experiences in solving meaningful engineering problems. Specifically, the following knowledge and skills/processes are being targeted (adapted from Cunningham & Hester, 2007):

Knowledge of: • What engineering is and what engineers do; • Various fields of engineering; • Core engineering ideas and principles and how these draw upon mathematics and science; • Engineering design processes; • The nature of engineering problems and their multiple solutions; • The role of mathematical models in solving engineering problems; • How society influences and is influenced by engineering; and • Ethical issues in undertaking engineering projects.

Skills/Experience in: • Applying engineering design processes; • Applying science and mathematics learning in engineering; • Employing creative and careful thinking in solving problems; • Envisioning one’s own abilities as an engineer; • Trouble shooting and learning from failure; and • Understanding the central role of materials and their properties in engineering solutions.

Surveys

Student and teacher surveys were developed for the grade 7 classes and implemented at the beginning of the school year (2009). The student surveys focused on their experiences with, and views on, their classroom mathematics and science activities. The teacher surveys asked for their perspectives on teaching mathematics and science, the amount of support their school provides, and their views on integrating subjects and introducing engineering experiences. We report here on the student survey results only. In addition to providing us with some baseline data for reviewing the students’ progress at the end of the first year, the surveys enable a needs analysis of the students’ science and mathematics learning prior to implementing the engineering activities.

The student surveys comprised two parallel formats, namely, one that addressed mathematics and the other science. Students completed one of these two surveys, as indicated below. The surveys were modified from those used by Byers and Dawes (2007), which in turn drew upon the survey instruments of Fry, Reed Rhoads, Nanny, and John O’Hair (2003) and Roelofs and Terwel (1999). The modifications to the present surveys included separating questions that combined both mathematics and science issues and refining some statements to improve clarity.

Missing data were deleted from both surveys, hence, from 182 middle-school responses there were 172 completed mathematics surveys and 166 completed science surveys. The mathematics demographics (males = 110, females = 62) involved 20 middle-school students from an all girls’ school, 62 from a coeducation school, and 90 from an all boys’ school. The science demographics (males = 112, females = 54) involved 19 students from an all girls’ school, 73 from a coeducational school, and 74 from an all boys’ school. SPSS was used to determine descriptive statistics (i.e., percentages, means [*M*], and standard deviations [*SD*]) on both the mathematics and science survey data. An ANOVA was employed to determine gender differences between items included on both surveys. In addition, an exploratory factor analysis (EFA; Kline, 1998) was conducted to ascertain the possibility of common factors aligned with both the mathematics and science items.

Findings from the Student Survey

Table 1 displays the results from both the mathematics and science surveys. The abbreviated survey items 1-9 and 14-19 pertain to students' views/perceptions of their school/classroom expectations or experiences, while survey items 10-13 and 20-23 pertain to students' own views on their learning and perceptions of mathematics and science. An exploratory factor analysis extracted six factors from both the science and mathematics data, however, further investigation determined that statistical responses on survey items were not aligned for both these subjects; hence common factors mirrored on both the mathematics and science surveys may be ruled out. An ANOVA was also conducted to test the gender differences on all items of both surveys. In the mathematics survey there was statistical significance for Items 16, 17, and 18 ($p<.005$; Table 1). There was also statistical significance on the science survey for Items 5, 16 and 18 ($p<.05$). Items 16, 17, and 18 relate to group work in the classroom, where it appears that boys are involved in group work more than girls. It may be that boys perceive what constitutes group work differently from girls or a certain culture exists for boys' involvement in group work. Item 5, which refers to the teacher outlining steps to solve a problem, also seems to be more the case for boys than girls.

Table 1. Middle-year student responses to their learning in mathematics and science

Survey item	Mathematics (*n*=172)			Science (*n*=166)		
	%*	*M*	*SD*	%*	*M*	*SD*
1. New ways of thinking/doing	89	4.17	0.62	86	4.11	0.66
2. New ideas and activities	89	4.28	0.76	94	4.40	0.76
3. New ways of looking at things	91	4.36	0.70	83	4.14	0.76
4. Work independently	77	4.04	0.89	68	3.81	0.93
5. Steps to solve problems	83	4.22	0.88	81	4.10	0.81
6. Memorise terms and formulas	48	3.41	1.00	40	3.26	0.93
7. Decide on our own ways	56	3.58	1.09	43	3.35	0.97
8. Ask lots of questions	77	4.01	0.93	70	3.84	0.97
9. Relate to everyday life	55	3.50	1.03	61	3.36	0.91
10. Enjoy classes	71	3.92	1.15	81	4.15	0.86
11. Give things a go	83	4.09	0.82	90	4.36	0.80
12. Enjoy coming up with new ways	67	3.80	1.05	69	3.92	0.90
13. Learning will be useful	83	4.34	0.91	63	3.84	0.96
14. Talk about topics	37	2.99	1.17	28	2.93	1.05
15. Experiences outside of classroom	55	3.52	1.02	63	3.64	0.92
16. Allows to solve problems in groups	58	3.56	1.19	78	4.01	0.96
17. Help each other	56	3.52	1.09	61	3.54	0.96
18. Work with other students in teams	38	3.16	1.17	58	3.60	1.06
19. Students help review work	38	3.22	1.06	40	3.20	0.95
20. Important to do well	96	4.66	0.69	83	4.28	0.84
21. Useful in real life	96	4.70	0.61	83	4.23	0.82
22. Usually do well	80	4.08	0.91	70	3.83	0.78
23. Like a job	46	3.34	1.25	31	3.01	1.27

* %=Percentage of students who either "agreed" or "strongly agreed" with each item.

Students' perceptions of their schools and classroom expectations indicated student-centred learning was a focus within these schools. It appeared that these students were encouraged to explore new ideas and develop independency in both mathematics and science. They were also encouraged to ask questions, with teachers facilitating activities related to the real world. The majority of students indicated that they enjoyed their classes in mathematics and science, and considered it important to do well in these subject areas.

Fine-grained analysis of students' perceptions suggested similarities and differences between their responses in mathematics and science. For example, the majority of students agreed or strongly agreed with 17 of the 23 items. Response differences occurred with Items 6, 7, 14, 18, 19, and 23. In general, students believed they were not required to memorize terms and formulas nor did they talk about topics from other school subjects or have peers review their work in either mathematics or science. From these students' perspectives, working with other students occurred more in science (58%) than mathematics (38%). Conversely, deciding on their own ways for problem solving appeared to be greater in mathematics (56%) than in science (43%) with 20% more claiming that learning mathematics will be more useful than science (Item 13). It was almost unanimous that it was important to do well in mathematics, as learning in this subject was considered useful for real-life situations (Items 22 & 23); yet 10% more students claimed they enjoyed science classes more than mathematics (Item 10; Table 1). Finally, 15% more noted a job prospect that utilizes mathematics (46%) than a job prospect in science (31%).

We considered this initial context analysis to be essential for determining perceptions of students' learning in mathematics and science in our efforts to situate engineering education in a school system. The present schools appear to have a structure that supports mathematics and science learning, and these foundations can allow for an easier transition to engineering activities. This preliminary information also provides a way for us to compare and interpret later learning. For example, conducting the same survey as a posttest after facilitating engineering activities may provide valuable insights into how students relate mathematics and science to engineering. The survey could be further developed and refined (e.g. removing any repetitive items such as 9, 13, and 21) to focus on factors that may best represent such contexts for learning.

Concluding Points

Engineering education in the primary and middle schools is in its early development. Recent research, however, is providing innovative ways in which to integrate engineering experiences that draw upon students' existing mathematics and science curricula. In establishing this emergent field, researchers are posing a number of core questions that warrant attention, including: What constitutes engineering thinking for primary/middle school students? How can the nature of engineering and engineering practice be made visible to young learners? How can we integrate engineering experiences within existing school curricula? What engineering contexts are meaningful, engaging, and inspiring to young learners? and What teacher professional development opportunities and supports are needed to facilitate teaching engineering thinking within the curriculum? (Cunningham & Hester, 2007; Dawes & Rasmussen, 2007; Zawojewski, Diefes-Dux, & Bowman, 2008; Kuehner & Mauch, 2006; Lambert et al., 2007).

Building a program of research in a developing field such as engineering education requires an innovative interdisciplinary approach (Carrick Institute, 2008; Lesh, 2008). The recent Australian Carrick Institute Report, *Addressing the Supply and Quality of Engineering Graduates for the New Century* (March, 2008) highlights the importance of developing partnerships among engineering and education faculties, school systems, and industry to develop contemporary engineering resources to support school-level mathematics, science, and technology. Indeed, the answers to the above questions cannot be addressed effectively without drawing upon expertise in several domains. We consider the involvement of outside industry partners especially important as they can provide first-hand, real-world engineering experiences for school students. Likewise, the participation of undergraduate engineering and mathematics and science education students is a valuable asset to school engineering programs. Recent research (Byers & Dawes, 2007; Dawes & Rasmussen, 2007) has shown how the engagement of such undergraduates in actual classroom activities led to positive gains by all stakeholders, with classroom students connecting with young inspiring engineers in context-rich, group-based activities. Indeed, engineering communities are stressing the importance of finding "better mentors and role models, making engineering 'cool' and accessible for all constituencies, especially females and minorities" (Douglas, Iversen, & Kalyandurg, 2004, pp. 13-14).

Further research on investigating connections between mathematics, science and engineering at the middle-school level is needed. Our project is one starting point here. The existing scant research suggests that fusing curricula such as science and mathematics as a way to further engineering education may also benefit middle-school students' learning in science and mathematics (e.g., Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006). To maximise students' learning, however, engineering education in middle schools must enter at the foundational levels of teaching engineering. Hence, preservice teachers' learning on how to teach engineering will be pivotal to the process. In addition, collaborative work between education and engineering faculties may further enhance the prospects of developing engineering education, particularly the fusing of concept knowledge from engineering experts with effective pedagogical approaches from teachers and teacher educators. Indeed, further research needs to incorporate collaborative partnerships (e.g., engineering lecturers and undergraduates, educators and preservice teachers, and teachers and students from middle schools) for devising engineering activities that may be trialled and tested within middle-school settings. Building a strong, collaborative international community for engineering education research is another key factor for promoting engineering in schools. Such a community is already emerging with new sites being established around the globe (e.g., Oware, Duncan, & English, 2007 [Purdue University]; English & Mousoulides, in press [University of Cyprus]).

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