Influencing Student Designers Towards Safe Design:- Transdisciplinarity and the Journey of the Devox

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***Abstract**: Could a change of paradigm be developed in future designers (students) to incorporate people at the original concept stage of the design cycle to create safe design? An action research project with a transdisciplinary approach was used to embed an ergonomics philosophy within the technical framework of the engineering design cycle for engineering students. This paper reports the learning from five cycles within a transdisciplinary environment. The learning model has positively impacted on the practice of current students.*

The most encouraging findings from this research were that undergraduate interventions did change the professional practice paradigm of early career engineers. The research also lays the foundation for developing continuing professional education models for current professionals, which refocuses the design process on human centred engineering design.

Setting the Scene

Ill-informed engineering design significantly contributes to accidents where latent sources of human error are a major factor. These accidents were historically blamed on end users. An investigation of this issue by Toft (1998) revealed that engineering educators and practising professionals in Australia are not educated in the importance of human factor aspects of design usability.

In it's 1995 report, *Work, Health and Safety*, the Industry Commission, based on research by the Australian Bureau of Statistics, estimated that every year in Australia there are over 500 fatalities as a result of traumatic injury at work; between 650 and 2200 workers die of occupational cancers, and up to 650,000 workers (that is, one in every 12 workers) suffer illness or injury at work. The social and economic cost of these injuries and illnesses has implications for the individuals involved, the employer and all Australians. For the individuals and members of their family the resulting loss of quality of life can be significant and not easily measured.

A study by Reason (1990), examined several major technological disasters including Three Mile Island, Bhopal, Chernobyl, and the space shuttle Challenger, and found that latent failures now pose the greatest threat to high technology systems. These latent errors which manifest as human error on the part of the operator were actually found to be most often generated by the designers and high level decision makers during the system's development (Reason, 1990). The potential for disaster may lay dormant for many years until the combination of local trigger mechanisms reveal the breach in the system's defences.

There would appear to be therefore, evidence of a knowledge gap in professional engineering practice with regard to understanding design error. Technological failures do not simply occur from incomplete or inaccurate computations. System deficiencies can also be caused by a failure to remove or control a hazard or by an omission to incorporate desirable features into the design (Hammer, 1989). Norman, expressing the sentiments of many consumers, asks:

Why do we put up with the frustration of everyday objects, with objects that we can't figure out how to use, with objects that seem impossible to open, with doors that trap people, with washing machines *and dryers that have become too confusing to use, with audio-stereo-television-video-cassette-recorders that claim in their advertisements to do everything, but that make it almost impossible to do anything? (Norman, 1988)*

The highest return for investment of human factors analysis is at the concept phase of a product. Mayhew (1992) found that the benefits would include decreased costs for providing training, customer support, development, maintenance, training time, a decrease also in user errors and user turnover. Other benefits found which can be costed quantitatively, are improved quality of service, increased sales and user productivity.

What's the Real Problem?

The authors are both educators and researchers in the area of professional practice paradigms. Our problem concerns the relationship between ergonomics and engineering professional practice and education in terms of the Australasian experience. Our context with regard to engineering professional practice is design work that is performed by engineers in industrial environments where there is traditionally little interaction between the engineering designers and the professional ergonomics community (the situation that the majority of our, and other, graduates will find themselves working in).

Safe Design is a term used for the design of engineered products and systems. Safe Design is such a simple term, but in reality it has many complications. The term simply means the development of products and systems that have minimised risk and reduce harm to their users. Safe Design allows for a better designed-product with more predictable business costs – whether in production, construction, manufacture, use or work systems.

The Contradictions

Within the domain of our research, there are many issues to be addressed. Many of those issues are simply based on contradictions that must be resolved. The major contradictions that we have met with regard to safe design and directly relating to engineering education are:

- Engineers do safety to death, yet we have over 500 people per year die in workplaces in Australia
- We have no time to introduce more content into the curriculum, and yet technology and knowledge is increasing at a faster rate than we can teach it
- 1996 Australian review encourages cultural change and so does the resulting Australian accreditation document however the accreditation team does not necessarily require these changes
- Those who teach engineering are usually not industrially focused and yet that is what programs should be about. Many engineering educators are traditional and yet the profession is moving forward – the profession is ahead of the university – in relation to practice
- Requirement for interdisciplinary team work, and yet program does not have time, and emphasis on assessment is on the individual
- Workers are aware of the danger issues in the workplace, yet many issues are ignored
- Graduate engineers must be knowledgeable about ergonomics and safety issues, yet current academic staff are not
- Courses concentrate on technical problem solving, but many real problems are people oriented
- When people are considered in the design process, the result is still not satisfactory.

Design induced end user error plagues sustainability of systems, artefacts and equipment - solutions address downstream answers but do not address upstream issues - what do engineers know and need to know about the people in their systems? How can we most effectively teach future engineering practitioners about people in their system? How can we ensure that they are prepared to understand and take responsibility for 'good' design? How can we ensure safe design? This research paper focuses on one aspect of how the research team attempted to influence the future engineering designers - the students.

The Devox

The hero of this journey is the 'Devox'. Mathews and Wacker (2000:73) describe the devox as "an innovation virus with a voice", they go on to explain "… the devox describes how deviance … is expressed as it vectors across a fixed, linear, predictable, and measurable passage … ".This research came about when the individual devox of each of the two authors

- to develop engineering graduates who understood the profession and the meaning of professional practice as opposed to simply gaining a tool box of useful but isolated technical and professional skills.
- Who is informing design decisions about the people / system relationship in Australasian industry and how could this best occur and what strengths, challenges, threats and opportunities would need to be addressed

met and joined to become a single devox. It is important to recognise that the development of the problem definition is an iterative process. The initial aim of this project was to design a process that would allow ergonomics to be incorporated into the undergraduate engineering program of study, without increasing content or workload. The challenge of this exercise was to exploit the nexus between technical rationality and social responsibility. Challenging the thought process of future designers (and their educators) to incorporate people at the original concept stage of the design cycle became the problem definition.

Informing the Process

There can be little doubt that there is a global movement toward a Mode 2 research and learning environment. That is, a move toward socially robust, collaborative research, centred on problem solving. However, as academics and researchers, there is still pressure to conform to a Mode 1 research paradigm, that is, individual disciplinary centred research or as disciplinary researchers interacting with each other in a Mode 1 framework in a multi or interdisciplinary mode. 'Disciplinary' approaches are a product of our learning within a discipline, the paradigm of practice created and accepted by any given discipline. The transdisciplinary approach starts with a real world problem and then draws on the expertise inside, and outside, of academia to develop mutual learning, and develop solutions to address a given problem. The team is seamless in the approach, and works in a different space to any of the traditional disciplines and knowledge domains within the team. There is an explicit commitment to a higher ideal, to sustainable outcomes. The outcome is creation of new knowledge that does not necessarily fit the traditional research outcomes of any / all of the disciplines involved. This approach is however complementary to disciplinary approaches and offers an alternative opportunity for problem identification and solving.

Nicolescu's (1998) three pillars of transdisciplinarity – levels of Reality, the logic of the included middle, and complexity – are the basis of the transdisciplinary approach. Considering the contradictions existing in our current reality, and the complexity of cultural change, this research uses the concepts of transdisciplinarity to develop a solution to the stated problem..

Levels of Reality

Henagulph (2000) describes reality as *"that which resists our knowledge, experiences, representations, descriptions, images or mathematical formalizations"*. The different levels of reality relate to realities where the same fundamental laws do not apply. An example of this is quantum and classical physics. At the Quantum level of reality, the fundamental laws are not the same as the classical laws of the macrophysical level. Henagulph (2000) goes on to explain further that the passage from the quantum level of reality to the classical level of reality can be seen in terms of a phase transition, in much the same way as a change from a solid to a liquid is a phase change. It is further explained that the phase 'transitions of Reality' can be described by the logic of the included middle as formalised by Lupasco (n.d., cited in Henagulph, 2000).

The Logic of the Included Middle

Our scientific or classical logic is based upon the following three axioms:

1. The axiom of identity is : *A* is *A*
2. The axiom of non contradiction: *A* is not *non-A*
3. The axiom of the excluded middle: There exists no third term *T* which is at the same time *A* and *non-A*.

The concept of different levels of reality, changes this, and creates the logic of the included middle, which allows for the third term *T* to exist. This third term *T* can exist in a reality which is different to the one we are currently working in.

Complexity

Complexity, according to Henagulph (2000) is a system paradigm. Complex problems demand complex thought. It is a mistake in this time of chaos and complexity to attempt to reduce all problems to the most simple, and find simple solutions. It is far safer and more productive to recognise the complexity of the situation and develop different ways of thinking and problem solving. Henagulph (2000) suggests that

In order to organise the increasingly complex nature of knowledge we need to develop a form of recursive thinking. This is a mode of thought capable of establishing a dynamic and generative feedback loop between terms or concepts…that remain both complementary and antagonistic. Although this initially seems impossible, once one has comprehended the different levels of Reality, and their associated logic of the included middle…it becomes much clearer how to proceed.

Problem solving approach

As our education is based upon the knowledge base of our profession, if there exists a problem that is outside the realm of the profession, and therefore outside the realm of our own educators, there is a good chance that the ideal solution will not be found. The solution may lie in an alternative reality. If we are to achieve safe design, we must find the alternative reality where the contradictions become the third term *T*, and are no longer contradictory.

The method used is a hybrid methodology that uses an action research process as a vehicle while incorporating the principles of other methodologies to assist in the iterative steps. The methodology used for this research is a transdisciplinary approach, that is, an approach that fosters joint solving of complex problems across science, technology and society - as is appropriate for our disciplines. Transdisciplinarity requires that stakeholders participate from the beginning and remain active over the entire course of the project and mutual learning is the basic process of exchange, generation and integration of existing or newly-developing knowledge in different parts of science and society (Klein et al, 2001).

Action Research

Action Research (AR) is a cyclic process of problem definition, enacting a potential solution, observing the impact of that action, and finally reflecting on the outcome, and then repeating the cycle.

Carr and Kemmis (1986) suggests that

… The methodology of action research is a cyclic form of selfreflective inquiry. It is used in social situations by the participants, to improve their own practice and the understanding of their practice and the situation (Carr and Kemmis, 1986)

According to Herr and Anderson (2005), AR is the method often used for researching one's own practice, also known as 'self study' or 'autoethnography'. They say that in AR, the emphasis is on narrative or self reflective methods. AR is different to many other methodologies in that it does allow the practitioner to be a participant. As noted by Fecho (1995, cited in Herr and Anderson, 2005:35), *"An insider perspective – a perspective too rare in the current literature"*.

While the insider perspective has much to offer in the way of new knowledge, that participation must be acknowledged for it to be valid. As Herr and Anderson (2005:35) also note

"We find it difficult and perhaps deceptive to attempt to separate the study of one's self and practice from the study of the outcomes of actions initiated in a setting".

For the reflective practitioner (Schon, 1987), that is, one who learns to learn about their practice; action research using the 'insider perspective' may well be a useful methodology. McTaggart (1989) suggests that participatory AR is an approach to improving social practice by changing it and learning from the consequences of change. It is research through which people work towards the improvement of their own practices and only secondarily for the improvement of other people's practices.

Therefore, initially in this project the participatory AR model was a suitable model for us, as many of the concepts in the early cycles were concentrated on determining if the concepts were suitable by reflecting on how they had impacted our own practice. A maturation of the process was required, and an additional overlay was required.

Soft Systems Methodology

The Soft Systems Methodology (SSM) as described by Checkland and Scholes (1990) allows us to overlay the political and cultural issues that cannot be removed from the context of the research. The private and professional practice space in which we both work was influencing not only the decisions that we were making, but our reflections on the outcomes of each of the cycles. The reflective process in each cycle was demonstrating to us that we could not divorce even the private and personal issues that we were both experiencing from the outcomes of our reflections.

A hybrid problem solving approach

The hybrid was Action Research and Soft Systems Methodology embedded within a Transdisciplinary Design Process. The methodology used in this project was a combination of the design process within a transdisciplinary environment with action learning to allow reflections and growth within the cycles, and Soft Systems Methodology to incorporate the political and cultural issues that informed the context.

The action learning allowed an evaluation of the concept designs against the problem definition and informed the team of the growing understanding of the 'real problem' at each stage. The SSM promoted recognition of the political and cultural issues that impacted upon the problem space. It was the SSM that informed the new problem space from cycle to cycle. It was important to realise that the context of the problem did actually change from cycle to cycle. The environment and hence the context was not static over the period of the project.

Data Collection and Analysis

The data was drawn from five iterative cycles of problem solving and the subsequent learning from 1998 to 2006. A set of criteria were developed to assess each cycle.

In each cycle the issues examined were:

- Context of the problem space:
  - Our perceived political/cultural reality during that cycle;
  - Issues that were affecting our paradigm of practice from multiple perspectives – engineering, ergonomics, education and the experiential knowledge gained from the previous cycle; and
  - Issues that added technical complexity to our problem space.
- Environmental Context (and influences on) 'our' practice space:
  - Our public practice space as we perceived it; and
  - Our private practice space which included influences from our individual and collective private worlds that impacted on our practice.
- Key actors in our network at that time who become transient (and sometimes not so transient) transdisciplinary partners in our research or influenced the passage of our devox in an important way.

We then used the previous reflections to discover any tensions that arose from the problem/practice space. This led to the new central question and any changes to our problem definition. Finally we outlined the concept solutions that we thought could further the passage of our devox and the iterative models to be trialled in that cycle. This leads to an outline of our major learning from the concept feasibility analysis that informed the next cycle.

The table in Appendix 1 summarise the models and outcomes and learnings for each cycle.

Findings/Conclusions

The use of an action research methodology enabled a reflection stage in each cycle that allowed the aim of the project to change as new observations were made.

The original aim had been to produce an awareness of the interrelated disciplines of engineering and human factors. At the conclusion of the first cycle it was obvious that the aims had been achieved, in that awareness had been raised but students were not integrating this new knowledge into their work. Reflection demonstrated that the aims were not congruent to a systems approach and were too limiting.

The second cycle began with the aim to develop socially conscious engineers and technically conscious OHS professional utlilising a Project Based approach. The implementation phase of this cycle failed to produce an integrated solution due to dissimilar preparation of students and failure to link learning outcomes. The traditional discipline based education encouraged the students to consider a solution only from the context of their own discipline. This encouraged inward looking, one-dimensional results, whereas the multi-disciplinary approach is expected to promote an outward looking, innovative and holistic approach to problem solving. The advantage of using project based learning in the multi-discipline environment, is that context can be given to the student learning. However this cannot be accomplished by simply requiring the two groups to work together on a project. A challenging curriculum, with shared goals and learning outcomes, and the necessity of an integrated team approach, is needed if the multi-disciplinary teams are to produce an optimum outcome.

We had expected to inform the development of human centred engineers who considered people as an integral part of any system. Through our own learning in this cycle, we realised that we were on the way to achieving this goal. However what we had achieved was, socially aware technologists.

With the third and fourth cycle, we found that the resulting projects bore the hallmarks of transdisciplinarity. The professionals produced by this learning community were different than those that went into the learning community. Communication was now occurring by multiple modes across and within teams. However, there was still a need by some teams and individuals within those teams to feel competitive with other team members and with other teams.

The outcomes of cycles 3 to 5 showed both us and our students that our ‘reality’ had transformed and that we would never be able to remove the new ‘lens’ that was now an integral part of both our and our students practice paradigms. As researchers we now have an understanding that a fused epistemology is not so disparate in nature from the original disciplines. This is hardly surprising since throughout the journey we have strived to maintain the authenticity of the research problem to both disciplines. For us, the new lens is not about throwing away the old discipline but rather overlaying the lens to optimise the development of design processes in normal engineering and ergonomics practice for our students. Safe design practices can be developed in engineering and ergonomics students, without the need for introduction of new content or extra workload, by the introduction of transdisciplinary teams.

Recommendations

The outcome of this research lays the foundation for developing continuing professional education models for current professionals, which refocuses the design process on human centred engineering design. Teams must seek to understand the alternate realities that exist for members of their team and strive to find the ‘included middle’ which will nurture the interdependence that is crucial to a transdisciplinary outcome.

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Appendix 1

Table 1: Summary of cycles and outcomes.

Cycle and Model	Outcomes
Cycle 1 Model - Multidisciplinary (Solar car) It was planned to expose students of the two disciplines to each other, in such a way that it would promote cross pollination of ideas and knowledge. They would teach each other about their disciplines, with the teaching team taking a facilitating role. Second year human factors students worked with first year engineering students on a design project. This necessitated the development of a linked project, which would allow the development of the discipline defined technical and generic skills for both groups of students, while encouraging synergy between the two disciplines. In 1999 the two groups of students were brought together to design the drivers' cockpit for a solar racing car. A team of engineering students was paired with a team of OHS students, to design the new cockpit. The intention was that the students would work in a combined multi-disciplinary team, and apply the principles of co-operative learning to learn from each other.	• two disciplines working as two groups with a somewhat tenuous interface, not as a single team • simply giving them a joint project would not engender a joint goal to be achieved • two groups working concurrently to achieve separate goals and coming together at the end to join the findings together • human factors considerations becoming a retrofit to the engineering design decision making • working as individual disciplinary practitioners - even the most generous reflection could only describe them as multidisciplinary teams • we did not take into account that the students had no contextual experience to draw on • we had consciously taught each other about our language, problem solving and cultural differences and through wanting to achieve a joint goal we had found common ground • we failed to give the students common ground or a common goal.
Cycle 2 Model - Interdisciplinary (Rock climbing apparatus) Developed in 2000 and implemented in 2001 as a refined version of cycle 1. The model was the development of two courses that could be fully linked and integrated. Mechanical System Design was offered for the first time in 2001, and therefore was developed specifically to facilitate shared learning outcomes with the Human Factors course. The learning outcomes and associated learning activities in the course Human Factors were modified to enable it to link in with Mechanical System Design. At the same time a common module was incorporated in both courses as foundation for the student teams. The link is a term long design project (accounting for 50% of the assessment of both courses) that had been specifically crafted to require discipline specific input from both disciplines for a successful outcome. In this model a specific client problem was given to the students as a starting point to the project.	• Most of the student teams had developed their members into human centered engineers • There were a limited number of exceptions and these were in the case where the engineer and ergonomists gave all decision making power to the engineer-effectively the human factors input turned into a retrofit • Students who did this reverted to what had been perceived by the team as norms for the engineering and ergonomics professionals. • the model and concept is very sound but needs tweaking to optimize the functionality.
Cycle 3 Model - Transdisciplinary (Open ended client brief) Implemented in 2002 as a modified version of cycle 2, this model was again the linking of the two distance education courses - Mechanical System Design and Human Factors. In this model a	• Acknowledgment of the virtues required to work in such heterogenous teams effectively. • a new reality was emerging in this transdisciplinary paradigm • Most of the student teams had developed their members into

client problem was open ended, in that the students were required to identify a community need as a starting point for the project. The students were required to identify the project, define the problem, develop concept solutions, and finalise a paper based detailed design. In this iteration of the model, the students were provided with an on-line environment to use for communication tools that made it easier for the interdependence and interaction to occur. The communication tools were so effective that it was no longer necessary to organise the teams by geographical location, and one team consisted of members that all came from different states of Australia.	human centered engineers. • the resulting projects bore the hallmarks of transdisciplinarity. • The professionals produced by this learning community were different than those that went into the learning community. • Communication was now occurring by multiple modes across and within teams. • there was still a need by some teams and individuals within those teams to feel competitive with other team members and with other teams. • What this model demonstrated was that unstructured / uniformalised critiquing had some value but there would be benefits in formalising this relationship if we wanted optimal outcomes.
Cycle 4 Model - Transdisciplinary (Open ended client brief - separate disciplinary teams – transdisciplinary critiques) In 2005, the need for a modification to cycle 4 was forced upon us. This was brought about by the declining numbers in the Bachelor of Engineering Technology program, the source of the engineering students for the project teams. The numbers had reduced so far in comparison to the human factors students that in 2005, there were not enough engineers to place one in each design team. This situation was not known until a matter of days before the courses were to start. It became clear that the previous model, while proven very successful, could not operate in this environment. We had no choice but to create teams based on discipline rather than crossing disciplines. The transdisciplinary approach was achieved by asking the disciplinary based teams to critique the design concepts of other teams. In this manner we were imitating the professional environment that many of our students would find themselves in upon graduation. We asked the students to follow the design process as before, and identify a community need, and determine the real problem, and then to identify possible concept solutions. After analyzing the feasibility of each concept they were to select and justify one concept for further development. As the teams still had to identify and meet both the engineering and the human factors requirements of the problem, they were going to need to access information regarding a discipline that was not represented in their team. Using the on line learning management environment, and its communication tools, we asked the student teams to use each other as consultants to help identify the deficiencies in their designs. The students were then asked to submit their concept designs for critiquing by all the other teams. Following the critiquing, the students were to submit a reviewed concept design. As the teams did not have all the specific discipline knowledge they required for a full paper design, we decided to limit the design process to the concept design, but to require a more fully fleshed out concept design.	• This cycle brought about some unexpected and at the time unwelcome changes to our concept. • we had been traveling down a path that had been so successful that we were becoming blinded to the alternatives that could be considered. • We were trapped in what we had developed as our own new discipline – the transdisciplinary team • The enforced changes however demonstrated that there are many models that may work, and in this case there were some marvelous highlights. - The students were using each other as consultants, and in doing so were playing both the designer and the consultant to another discipline, mimicking the roles that they may play in industry. - Many of the students actually found the critiquing phase the most informative and exciting phase - . While it was stressful, they also enjoyed the opportunity to discuss the advantages that their discipline could bring to another team's work. A team of human factors students was able to gain some very enlightening information on possible materials from an engineering critique. The critique allowed them to identify a new solution Without the critique they were having trouble meeting the requirements of the problem definition they had identified. - It was also supportive for them to have feedback on their work from their peers. Their reflective journals demonstrated the value of the critiquing phase to their overall learning. • Upon reflection, we found that we had discovered a model that would be valuable for us as educators to cover the uncertainties of enrolments, while still affording the students a transdisciplinary experience.
Cycle 5 Model - Transdisciplinary (Open ended client brief - separate disciplinary teams – transdisciplinary critiques reduced need for paper design) In 2006, the need to refine Cycle 4 was required. The approach taken in the previous cycle had been very quickly developed, and the reflective phase allowed us to consolidate the model. Additionally the numbers in the Bachelor of Engineering Technology (BET) program were reducing further, to the point where there were only two students enrolled in 2006. We once again had no choice but to create teams based on discipline rather than crossing disciplines. The model from the last cycle was implemented again, but this time the critiquing component that had been so successful was integrated into the process and the assessment of the course. We were still imitating the professional environment that many of our students would find themselves in upon graduation.	• The BET program was no longer what was required in industry, and students in the program were waiting to see if they could articulate into the new Bachelor of engineering (BE) program to be offered from 2007. • The faculty recognized that the transdisciplinary design projects had been successful • The transdisciplinary projects were being transferred into the BE program

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