AC 2009-2395: VIRTUOUS REALITY: THE DEVELOPMENT OF SAFE DESIGN THROUGH TRANSDISCIPLINARY TEAMS

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Virtuous Reality: The Development of Safe Design through Transdisciplinary Teams

Abstract

The development of safe design as an aspect of professional practice has been the impetus for an action learning project, using an innovative teaching model at CQUniversity, Australia. This transdisciplinary, project orientated, teaching and learning model, brings together the two disciplines of ergonomics and engineering with a view to shifting the paradigms of engineering education to include human factors in design, and ergonomic education to include technical design issues.

The cornerstone of the project is the recognition and development of personal and shared 'virtues' within the project team and learning community. The defined virtues create a common language of communication and perception, person to person, to create a team dynamic and provide an integration of cultures for the effective integrated activity of disciplines – effectively developing a shared 'culture of character'. Transdisciplinary teams built on this foundation focus on joint goals in a safe learning environment and with a commitment to higher ideals.

There are various contexts that make up the 'reality' part of the project. The overarching reality is the contextual reality. The socio-technical context of the Project, which created the original impetus, is the real life lack of ergonomics/human factors input into the education of future engineering professionals, a lack highlighted by a national review of engineering education in 1996, and supported by further research. It is commonly accepted that latent error in engineering design causes accidents. This lack of ergonomic input needed to be addressed. The Project was designed to facilitate the necessary interaction and to provide future professionals in both disciplines with new, overlapping skill sets. Other contextual elements are sustainability, safe design, a systems approach and human centred engineering.

The Project has been through a number of cycles based on action research methodology. Different levels of disciplinary activity have evolved during the course of the project, ranging from disciplinary: within the defined discipline, multidisciplinary: between the disciplines, through interdisciplinary: across the disciplines and finally to transdisciplinary: between, across and beyond the disciplines.

This paper outlines the project and its outcome for the students and staff involved.

Background

This paper shares our learning from a broader research project which strived to inform a changed professional practice paradigm for engineering designers in Australia to effectively incorporate people as an integral design consideration from inception of the problem definition and original concept development. The research has evolved to include multiple paths of intervention and has a futures orientation.

The specific focus of this paper is one of the interventions which ultimately saw the students work in transdisciplinary project teams and collaborate to create a system that is optimal in engineering terms, and is an optimum design for all stakeholders who interact with it. This iterative design project has been through a number of cycles based on an action research approach over a ten year period from 1998 to 2007. Different levels of disciplinary activity have evolved during the course of the project.

What is the *real* problem we seek to solve?

We are both educators and researchers in the area of professional practice paradigms, one originally and engineer and one originally an ergonomist. 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).

Design induced end user error plagues sustainability of systems, artefacts and equipment – current approaches 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 engineering educators and 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?

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.

It is not just the ergonomists or OHS professionals who are concerned about safe design. According to Johnstone[1] about 7500 violent, unnatural or accidental deaths are reported to Australian coroners each year. Of these, approximately 200 are homicides. Johnstone goes on to say that

> *“Whilst the coroner’s work in the area of specific unsolved or ‘hidden’ homicides is important…it is in the area of health and safety that there is a need for a far greater level of work.”*

The concept of ‘safe design’ moves safety upstream into the conceptual phase of design. The fact that safe design relates to the design process of engineered products and systems however, automatically places the responsibility for the design in the lap of the engineering profession. The Engineering profession sees itself as providing a service to the community, which can in this case be considered the stakeholders. The Code of Ethics[2] of the Institution of Engineers, Australia, specifically states that engineers must put the interests of the community ahead of any other parties.

The Issues

Is current design safe? NOHSC[3] conducted a review of workplace deaths. The review suggested that in Australia there are on average 10 deaths per week in the workplace. A large proportion of these can be traced back to poor design of equipment or systems. Poor design in this case does not mean technically poor, but poor from a user's perspective.

The issue of usability has been recognized by human factors specialists. Human error is a significant contributing factor to the cause of accidents and lost productivity. Effective human interface design will increase the usability and productivity of a system; and the consideration of human factors in the design process will reduce the likelihood of human error, resulting in a safer, more efficient work environment for all stakeholders[4]. So incorporation of human factors in the design process is one method of addressing the individual's issues of usability in the context of sustainability. The outcome of this is that the engineering profession needs to understand the importance of humans as an integral component in system design.

Toft[5] found that simply preaching safety to engineers is a distraction and probably counter-productive to encouraging and achieving effective design. Engineers believe they are already doing the right thing by designing to the existing standards. The responsibility to eliminate hazards or control their risk rests at the source. This principle applies to all hazards that might impact on the health and safety of workers.

Occupational Health and Safety and human factors professionals use a risk management framework to identify hazards. To ensure safe design, engineers need to follow the risk management framework to ensure that hazards are not only identified, but are also eliminated at the design stage. The Australasian engineering profession has begun to address this human component through the introduction of the most recent National Generic Competency Standards[6] in 1999, which incorporate competency standards for design. However Toft[7] had already found that engineering educators have reported that they do not have skills and knowledge in the area of designing for human use, and would need to first learn themselves about ergonomic principles of design.

Research Methodology

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[8] suggests that

> *… The methodology of action research is a cyclic form of self-reflective inquiry. It is used in social situations by the participants, to improve their own practice and the understanding of their practice and the situation.*

Action research cycle one (1999): Disciplinary to Multidisciplinary

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. In other words, they would teach each other, with the teaching team taking a facilitating role. The approach taken was to allow second year human factors students to work 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. We proffered that if students from our disciplines worked together (as we did) on a real design project (as we were) that they would reach the understandings that we had. The joint student solar car project operated in a way that resulted in the two disciplines working as two groups with a somewhat tenuous interface, not as a single team as we had expected. We however, were working as a team. Our learning had not translated into their learning. We found that simply giving them a joint project would not engender a joint goal to be achieved the result was a splitting into two groups working concurrently to achieve separate goals and coming together at the end to join the findings together as a single report with the human factors considerations becoming a retrofit to the engineering design decision making. While being aware that they were working alongside another discipline neither group integrated any learning about each other's practices into their own practice. They were working as individual disciplinary practitioners and even the most generous reflection could only describe them as multidisciplinary teams. We realized from this cycle that if we wanted to encourage teams to work toward an integrated goal we would need to find a way to make the teams interdependent. A compounding factor was that the two groups had different experiences in their preparation for working in teams which lead us to the understanding that we would need to provide a common grounding in their team building development. An additional failure of this iteration of the concept was that we did not take into account that the students had no contextual experience to draw on (as we did when we started as a team) and that 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.

We had expected to inform the development of socially conscious engineers who considered people as an integral part of any system. Through our own learning in this cycle, what we now really wanted to achieve was 'human centred engineers', to move our students from multidisciplinary to an interdisciplinary mode.

Action research cycle two (2000 to 2001): Multidisciplinary to Interdisciplinary

Developed in 2000 and implemented in 2001 as a refined version of the first presentation. 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. All teams were given the same problem. For 2001, this project was specified as the design of a support frame and harness for a paraplegic rock climber (this is a real life project, identified as requiring a solution by several community groups in Queensland). As an interesting twist this client problem was the same as that given to engineering only focused first year BEng project in the term before so that comparisons could be in the handling of the problem by the two different cohorts.

Most of the student teams had developed their members into human centered engineers. The project outcomes were an outstanding success. 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. They reverted to what had been perceived by the team as norms for the engineering and ergonomics professionals. There may have been a breakdown in our communication as a team to our student teams about the role of disciplinary team members in interdisciplinary teams. We also realized that we needed to practice what we preached and improve the usability of our project outcome. Our learning from the cycle is that the model and concept is very sound but needs tweaking to optimize the functionality.

> *Overall I would have to rate this experience as one, which I hope I shall never have to endure again, solely because I did not achieve the result (a successful design) I was aiming for as a group. Despite this I am very glad that I have experienced this type of situation as I now have the experience to notice possible warning signs and or situations for future team correspondence and hopefully implement positive solutions / behaviour to minimise negative results. (3rd year Bachelor of Human Movement Science Student)*

Action research cycle three (2002 to 2003): Interdisciplinary to Transdisciplinary

We proffered that if students from our disciplines worked together as we did on a real design project (as we were) that they would reach the understandings that we had. We still believed that if we wanted to further the development we would need to find a way to make the teams interdependent, that is, striving for a common goal and that we would need to provide a common grounding in their team building development. We thought that this endeavor could be enhanced by better communication tools that made it easier for the interdependence and interaction to occur. The students available to us were studying in “flex mode”, which meant that some were studying part time at a distance (anywhere in Australia), and some were full time students based on campus.

> *“at the start it seemed an almost impossible task, but the way the teams had to form and communicate through the planning of the course made a task that was more attainable through each stage …” (3rd year Bachelor of Engineering Technology student)*

"... working together to achieve a common goal. ... Without the input from other member with varying knowledge appropriate advancements in the world cannot be made possible. Issues do not always revolve around a central stream of specialisation but rather incorporates a vast range of knowledge." (3rd year Bachelor of Occupational Health & Safety student)

"….meaningful collaboration of ideas that resulted in the creation of a marketable design innovation. ... design project with team members spread over distances in three different centres caused some concern and raised some interesting challenges. … Most of my learning came through new experiences of overcoming challenges through the process of communicating in an interdisciplinary team" (3rd year Bachelor of Human Resource Management / Certificate of Occupational Health & Safety)

The other element that we thought would be valuable in this iteration was the introducing the notice of a 'community of practice' which meant that by having the students work on different projects we could encourage peer learning across teams as well as within teams. We proffered that if students were given an opportunity to share their work in a non-threatening, non competitive environment that all projects could be enriched. We also planned to strengthen explicit attention to the personal skills and attributes required to be a useful and effective team member. We would use the reflective journals to assess ability to self reflect and grow their own skills as team members rather than to check on what they perceived as the value of other team members. This would be quite a departure from normal assessment of project based team work. This change would also include explicit attention to the virtues required for transdisciplinary teamwork to occur.

"… most important strength of this process is that students from different faculties who traditionally have not worked together have to work together to firstly identify a problem and to develop a highly innovative solution ... students using the other team member's knowledge and field of expertise to develop a solution ... all team members must work together and show each other respect, listen to each other and trust one another…this team process was a learning journey and I have gained an awareness and respect for the engineering students and their design process. This experience allows for the personal development of skills such as trust and the development of some team skills." (2nd year Bachelor of Environmental Science student)

Implemented in 2002 as a modified version of the last cycle, this model was the linking of the two distance education courses - Mechanical System Design and Human Factors. A common module was incorporated in both courses as a foundation for the student teams. The link was 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 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 finalize a paper based detailed design.

The students were placed in teams based mainly on their geographical location, ensuring however that at least one engineering student and one OHS student were in each team. In this iteration of the model, the students were provided with an on-line environment to use for communication. However the cumbersome nature of the 2002 version meant that most students used telephone, email and fax between their team members, and between the teams and us.

In 2003, the model remained the same, with two exceptions. The first was the welcome change in learning management system provider. The new online environment offered for the first time a tool that had the communication tools and usability that we had craved in earlier models. The communication tools were so effective that it was no longer necessary to organize the teams by geographical location, and one team consisted of members that all came from different states of Australia. In most teams however we still endeavored to ensure that at least two members of the team had the possibility of meeting face to face. Each team consisted of one Bachelor of OHS student, one Bachelor of Engineering Technology student, and the other three to four members came from these degrees and elective students mainly from the areas of Human Movement Science, Human Resource Management and Environmental Science.

> *"When involved in a group activity especially over a long distance, the most important factor is communication between group members, and also trust and respect between the group members and appreciation of each other's work." (3rd year Bachelor of Engineering Technology student)*

In both versions in this cycle we nominated the best student designs for the Australian Design Awards and Far East Asian Young Inventor's Awards.

We were now combining different disciplines and different study modes, but realized that the students required an effective communication strategy for asynchronous teamwork. As a further complication, we had variable computer literacy skills within the group, a large age range, and large variation in the time available to commit to working on the project. In this cycle, we concentrated our effort on acknowledging the virtues required to work in such heterogeneous teams effectively. This was the other component of the genesis for our team name – Virtuous Reality. The reality as spoken of previously related to a new reality that was emerging in this transdisciplinary paradigm and the virtues was acknowledgement of the virtues required to work in this new paradigm.

> *"Some of the qualities that our team members displayed were, offering and accepting constructive criticism, encouragement, exploration of ideas, all were assertive, showed a lot of initiative, self confident, sincere, organised, trust worthy, team player, pay attention and show interest and brainstorming..." (3rd year Bachelor of Occupational Health & Safety)*

We proffered that if students were given an opportunity to share their work in a non threatening, non competitive environment that all projects could be enriched. We also planned to strengthen explicit attention to the personal skills and attributes required to be a useful and effective team member. We found that the resulting projects bore the hallmarks of transdisciplinarity. The artifacts 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. This model did not address this issue (yearning) in any useful way. What this model demonstrated was that unstructured critiquing had some value but there would be benefits in formalizing this relationship if we wanted optimal outcomes.

Action research cycle four (2004 to 2005): Transdisciplinary

In 2004, the model continued very much as it had done in 2003 except the students were placed in teams based purely on their program of study. As the on line environment was proving to be an effective communication tool, it was no longer considered necessary to team students based on their geographical location. Once again we ensured that each team consisted of one Bachelor of OHS student, one Bachelor of Engineering Technology student, and the other three to four members came from these degrees and elective students mainly from the areas of Human Movement Science, Human Resource Management and Environmental Science. As this model was only 'tweaked' in this cycle the evaluation was the same in this cycle as for the previous cycle.

> *"... the positive bonds that develop between the individuals that have been placed together, may create a greater sense of personal achievement, and subsequently improve their moral and willingness to achieve a higher level of professionalism within their own field of endeavour. …. when confronted with having to deal with people from another work environment, the difficulties in appreciating what their input is to the common goal may create uncertainties. …. The terminology used by other disciplines to describe their individual input may sometimes cause confusion amongst the group. … Any improvements to a team effort must centre about improving communications within that group. Most of the problems within an interdisciplinary work group, or any group for that matter, lies within uncertainties and incorrect interpretation of verbal communication. Any efforts to improve this line of communication will improve the chances of group members reacting negatively to their own incorrect perceptions of an event or situation. (2nd year Bachelor of Occupational Health & Safety)*

In 2005, the need for a modification to the model 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.

> *"After receiving the unit material and seeing that a project was incorporated and it involved interaction with other disciplines at first I had mixed thoughts as to how it would all work out. ... In my current job role I have project managed and planned shutdowns in excess of ten million dollars. I can now appreciate the benefit of having assistance from other disciplines in executing a project of such a size. Some of the requirements needed under legislation require a large amount of time to research. By involving and associating other disciplines within a project a different aspect and option as well as the knowledge in areas that are needed for the execution of a well run project that will be cost effective to the principal ... I thought I had a fair knowledge on the needs and requirements for safety and comfort when it came to engineering requirements and design. The other students involved in this project described and showed me documented proof of features that should try to be incorporated into any design that was to be undertaken ... other benefits, such as materials … not so much looking from the cost of the materials as I was but from the environmental point of view." (3rd Year Bachelor of Technology student)*

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. Upon reflection we had been traveling down a path that had been so successful that we were becoming blinded to the alternatives that could be considered. In many ways we were trapped in what we had developed as our own new discipline – the transdisciplinary team. The enforced changes however demonstrated to us 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.

It was 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.

Action research cycle five (2006): Transdisciplinary to Disciplinary

From the reflections on the previous cycle, we recognized that our way of working in a transdisciplinary team is not always possible. There may not be the right mix of disciplines available, and alternative methods of achieving the same goal were needed. In 2006, the need to refine the model 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 enrolment numbers in the Bachelor of Engineering Technology (BET) program were reducing yearly, to the point where there were only two students enrolled in the design course in 2006. This was not a reflection on the program, but a reaction to the review and restructure of the program that was occurring. 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 transdisciplinary design projects had been so successful that they were being transferred into the BE program, with the transdisciplinary team being a major force in the new course development team.

Our Learning

We are now in a 'knowledge based' economy, where the production process (the realm of the engineer) relies on knowledge based activities. However, according to European Commission[9] it is better to talk about a 'learning' economy rather than a 'knowledge based' economy. This is because … *the high pace of change means that specialized knowledge becomes much more of a short lived resource, and it is rather the capability to learn and adapt to new conditions that increasingly determines the performance of individuals, firms, regions and countries.*

The concept of the two professions working together as an interdisciplinary group could have positive outcomes for the community. However, the real differences will be seen when the transdisciplinary teams of the two professions start learning together to develop and implement solutions. The European Commission[10] discussed the different types of knowledge – codified and tacit. The codified knowledge is that which can be passed on by being transformed into information. In this way it can easily be spread by publications or more easily by the internet. Tacit knowledge on the other hand cannot easily be transferred, because *"it has not been stated in an explicit form. One important type of tacit knowledge is skill."*

The community problem has been identified – safe and usable products and systems are required. The solution is not so easy. This is because we cannot simply codify the knowledge needed for the development of safe design. If that were so, then the human factors professionals could simply transfer their knowledge into publications or processes that the engineers could digest and follow. It is the tacit knowledge that the human factors professionals have that is required as well as the codified knowledge relating to processes that is needed.

What is required is a cultural change within the professions. While the governing bodies such as the Engineers Australia[11] may require its members to produce sustainable designs, if the knowledge does not exist, then the outcome is difficult. If the engineers and human factors professionals are to learn from, and work with each other, there is much groundwork to be covered. Where to start is a difficult question. It would be easy to sit on the beach like A. A. Milne's *Old Sailor*[12], and do nothing but bask until we are saved, but we need to be proactive and start identifying the 'learning' gaps, and start plugging them.

The undergraduates also need the opportunity to work in interdisciplinary, or preferably, transdisciplinary teams. If this is done at undergraduate level, it becomes easier to work in this manner as a graduate.

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