Human centred engineers - A model for holistic interdisciplinary communication and professional practice

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Abstract

There are many challenges facing graduate engineers in a rapidly changing world. Engineers of the future will require abilities previously not considered 'core' to their professional practice. This research is aimed at the development of an enhanced understanding of the human component in system development and operation in both engineering and human factors graduates. Consideration of 'human factors' in engineering design will reduce the likelihood of human error, resulting in a safer, more efficient work environment for all stakeholders. The synergy of practice of the two disciplines of engineering and human factors, through an innovative teaching model, such as the one currently being developed, will ensure that graduates from both disciplines will become leaders in their professional practice This model is being developed through an action research project. The findings indicate that the two disciplines must learn to work together during the entire design process. It is not enough to simply educate the engineers in the basics of human factors, and the human factors practitioners in the basics of the design process. True integration is needed to achieve the synergy.

Relevance to Industry

Current engineering education prepares graduates well in terms of technical solutions, but very poorly in terms of social design skills. This paper informs a paradigm change which will encourage continued technical reliability, but enhanced social responsibility.

Key words design, engineering, interdisciplinary, education, cooperative learning

"*The classic of all design deficiencies which have come to our attention was a combination safety shower and eyewash constructed at a northern missile site. In order to operate the eyewash, it was necessary for a man, who might already be blinded by acid, to put his head in the eyewash bowl and then to turn on the water valve with his right foot. The only problem was that the foot-operated valve was about four feet to his rear and higher than his waist. As an additional feature, if a man did happen to hit the valve, he got a full shower from overhead as well as getting his eye washed out. However, the whole problem became academic in winter because the whole system froze up." (Anonymous, 1959)*

1. Introduction

The influence of human factors in engineering design has not generally figured to any extent in engineering curriculum in Australia. A shared interest in this relationship led the authors to collaborate in providing ergonomic principles and safety related topics for engineering students in the latter part of their undergraduate program. Students interest in the topic was evidenced by the high level of interaction in the classroom, and the inclusion of related principles in subsequent projects. Some students questioned during the sessions why had they not been given this material before, as they believed it to be integral to their study of engineering design. In a recent survey by Toft (1999), it was found that 56% of the surveyed engineering academics did not believe that ergonomic principles were currently taught as part of the engineering curriculum, and a further 36% were uncertain.

If engineers need to understand ergonomics, it suggests that ergonomists should also need to understand the process engineers use to problem solve and design. At this point it was realised that these two groups of professionals should be capable of working

together and understanding not only the processes and goals, but the separate languages as well. Johnson (1996:198), claims that " … it can be difficult to communicate the findings of human factors specialists into a language that can be interpreted and acted upon by systems engineers, … problems can arise from terms that have a precise technical meaning in one discipline but also a more general interpretation."

At Central Queensland University a model for holistic interdisciplinary communication and professional practice is being developed to create an experiential learning environment which facilitates 'real life' problem solving, including consequences arising from the learners actions, in a safe and supportive environment. It's aim is also to develop generic and specific attributes of learners from complimentary disciplines toward a synergistic and enhanced interdisciplinary understanding in their professional practice.

This project involves an action research approach to develop an integrated and shared unit to provide common real life projects to be completed by interdisciplinary teams of students.

2. To err is human but which human?

Practicing professional engineers of the future will require abilities previously not considered 'core' to their professional practice. According to a review of engineering education steered by the Institution of Engineers, Australia (IE Aust 1996), future engineers will need to consider not only the specified operational needs of a system, but also, the abilities, capacity, expectations and understanding of users at all stages of the system life cycle from the concept stage through to decommissioning (Kirwan and Ainsworth, 1992). Effective human interface design will increase the usability and

productivity of a system (Jordan, 1998). Further to this, consideration of 'human factors' will reduce the likelihood of human error resulting in a safer, more efficient work environment for all stakeholders (Sanders and McCormick, 1993).

Ergonomic practitioners have for many years been challenged to communicate the need for their input into engineering design application at an earlier stage. The focus of this problem has been the lack of opportunities for this interaction to occur, and indeed convincing engineers that it should! The challenge is not necessarily overcoming objections but leading engineers to an awareness of the importance of ergonomics in engineering design (Toft, 1999). The key challenges which can, and do arise, is a perceived absence of common interface language and problem solving mechanisms. This research project is intended to establish appropriate communication models to bridge the gap between these two critical professions. The optimal outcome will include the development of an integrated approach to problem solving in a cooperative framework, which will benefit practitioners of both disciplines.

In an attempt to identify key components in the engineers professional education and practice which may be significant in terms of ergonomics, a job analysis was completed (Toft, 1998). The professional standards seek to embrace the content and process of sustainability. Broadly 'sustainability' in this context is an expectation of practising engineers to ensure that their work does not degrade, and strives to improve, the quality of life for this generation and generations of the future, and should include consideration of the agendas of social equity, ecological quality, and economic prosperity in relation to one another (Crofton, 1998). The significance of sustainability in the context of this research is the interrelatedness of the human, economic and other resources in systems planning and design to optimise quality of life. The greatest

benefit of ergonomic intervention occurs if integrated as early as possible in the system life cycle, therefore, consideration of the human factor in planning and design, will be significant in terms of human-machine interaction (Kirwan and Ainsworth, 1992).

There would appear to be evidence of a knowledge gap in professional engineering practice with regard to understanding the ramifications associated with user interface design error (Norman 1988). Any or all stakeholders can potentially contribute to accidents related to human error. There is a duty of care owed by designers and manufacturers under common law (Johnstone 1997), and workplace health and safety statutes. Legislative breaches can lead to high social and economic costs borne by both the designer, and business, for which the system was developed. Poor safety performance is likely to result in the threat, and potential reality, of increasing litigation.

Safety, although vitally important, is not always the most convincing argument that can be made with regard to cost / benefit analysis. The safer the system, the less accidents there are, therefore the less quantitative evidence (performance indicators) there is available, with which to argue the benefits of designing inherently safe systems. Human factors analysis is sometimes seen to be an extra expense which does not reap a monetary reward beyond the cost of the analysis itself (Wickens, Gordon and Liu, 1998).

There is, however, compelling evidence for the benefits of human factors intervention, in terms of cost, with regard to usability of products (Jordan, 1989). 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, and also a decrease in user error and user turnover. Other benefits found which can be

costed quantitatively, are improved quality of service, increased sales and user productivity.

3. What's the nature of the gap between disciplines?

Blockley (1996), describes the gap between technical and human factors:

"There are limits to the technical approach that are often unrecognized. At the scientific level the developments in modern physics, in quantum mechanics… have shown that there are distinct limits to what we know… The social science approach is broadly split into the individual (psychological) approach and the group (sociological) approach. It is often termed the 'soft' approach in scientific discussions. It is typified by informal models...Theories such as … those concerning human error … are descriptive, but nevertheless aid understanding" (Blockley, 1996:31-32)

He goes on to argue,

"…that these two 'world-views' urgently need to be integrated to a common purpose, recognizing that risk and safety are issues lying at the interface between the technical and the social…that the technical/engineering concept of reliability should be replaced by the social science/legal/management concept of responsibility." (Blockley, 1996:33)

The integration of the these two cultures in engineering can be enhanced by gaining an appreciation of the interface between equipment / operational environments and the quality of life of those interacting with the system.

There has been some research in Australia regarding the task of building in safety and health features at the design stage of equipment. Thatcher (1997) stated:

"…depends on the engineers', designers' and decision-makers' technical knowledge of ergonomics and OHS, and inappropriate education is one influence creating workplace

injuries and deaths. Occupational health and safety education however, must focus on developing problem-solving skills and innovation, rather than providing solutions which may be rapidly outmoded. Engineers play a key role in the design and operation of the workplace, processes and equipment used in today's society." (Thatcher cited in CCH, 1999, para 90-079)

In support of his argument he cited a survey conducted by the Victorian Institute of Occupational Health and Safety (cited by Thatcher 1997 in CCH, 1999), finding that engineers do not associate their occupation with causes of accidents regardless of their knowledge base, education or experience. He stated that the researchers used the examination of case studies and answering of a related questionnaire to collect data. These case studies were presented to both engineering and OHS student groups. The OHS students who were surveyed purportedly continually provided an opposite response to the engineering groups surveyed, which led the team to conclude that there is a need for the training of engineers to be enhanced by OHS education.

Ergonomic practitioners also can benefit from the synergy of disciplines. Lim (1999) suggests that to enhance the effectiveness of engineering design and human factors design practice and contribution, human factors practitioners will require a basic knowledge of industrial and engineering design to enhance the pertinence of design recommendations. He adds that effective human factors design recommendations will be made by practitioners that take a multi-disciplinary perspective, adopt a systems approach and embrace both the objective and subjective aspects of design. Ergonomic contribution will need to go further than functional aspects of design and objective user performance testing (Lim, 1999). Redmond (1994) purports that if ergonomists wish to engage in design activity they will need to acquire some understanding of the nature of

capabilities, culture and methods of design. This would require an understanding of the separate methodologies, cultures, values, aspirations and capabilities of ergonomists and designers (Redmond, 1994). Authors also highlight that the two disciplines tend to have different training and different goals, therefore different problem solving processes (Ward, 1990; Talbot et al 1999).

4. Bridging the gap! – A model for the human centred engineer

In 1996, the two disciplines of ergonomics and engineering began a relationship based on guest lecturing. The aim of the relationship was to give the engineering students an awareness of their responsibilities under the revised Queensland Workplace Health and Safety Act. The opportunity was taken at this time to also introduce generalist OHS guidance including an introduction to ergonomics. In 1997, the mechanical engineering design staff saw the opportunity to introduce ergonomics as a concept to design students. The introduction used case studies that highlight the link between design and human error.

In each case the aim was to raise an awareness of the importance of the human user within the design specifications. At this stage it was expected that the gaps identified through analysis of the available literature could be addressed by simply increasing awareness of safe design principles. To this end the information presented concentrated on two main areas, latent design error, and basic ergonomic principles and their application.

4.1 First Attempts – Awareness Raising

An action research methodology was employed to develop and evaluate the effectiveness of the attempt to bridge the gap. The action research methodology is a

cyclic process involving the following steps: plan, act, observe and reflect. The observation and reflection component of the cycle identified several outcomes.

1. The engineering students had developed an awareness of the existence of ergonomics, and the benefits of including ergonomic principles in engineering design
2. The research team no longer considered that an awareness was sufficient. The team wanted to develop students that actively considered humans as part of the system that they were designing - "socially conscience engineers"
3. The traditional lecturing pedagogy used to develop an awareness of safe design principles was not developing any understanding of the complexity of the synergy required. The material presented was simply an "add on"

> The outcomes agreed with Dearn who stated; "Much university teaching is conducted under traditional pedagogy where to teach is to transmit information and teaching consists of organising and communicating content. If the primary goal of a university education is to help students develop into independent learners then there are basic problems with teaching in a way that leaves students in a passive role and where the teacher is doing all the thinking. Teachers often find themselves almost unwittingly summarising, clarifying and comparing – in other words removing the opportunity for students themselves to practice these fundamental skills which are the essence of academic discourse" Dearn (1996).

In order for the engineers to be able to consider the human component of design, they needed to be critical thinkers. Critical thinking has the opportunity to develop when active, not passive learning is pursued. The reflection stage of the first cycle showed clearly that an active learning pedagogy had to be employed.

The reflection component of the research also identified a change in the focus of the research team. The research focus moved after the first cycle to explore ways of implementing a holistic focus to engineering design in particular. This required not only engineers, but ergonomists as well, to be part of the design process.

4.2 Linked Teams

The next cycle in the action research attempted to use collaborative learning, an active learning style, to have engineering and ergonomics students develop socio-technical solutions to design problems. In 1998 students from both disciplines were formed into multi-disciplinary teams to develop design solutions to real problems. Students from the two disciplines attended classes for their own discipline, but worked jointly on a design problem.

The observation and reflection process produced the following conclusions:

1. The two disciplines worked as two groups with a tenuous interface, not as a team.
2. While the research team were working as a team, the learning had not translated into student team learning
3. Within the multi-disciplinary research team, it was through continuous exposure to each other's processes, languages and viewpoints that the learning occurred.

The students were still operating in a traditional discipline approach to the problem. They were not attempting to teach each other in a collaborative format, but were attempting to exist wholly within their own discipline, and simply develop a solution to "their part of the problem". The traditional discipline based education encouraged inward looking results, whereas the interdisciplinary approach encourages an outward looking, innovative and holistic approach to design.

The research focus had now changed to developing "human centred engineers". While socially conscious engineers add people as another specification, human centred engineers, as Steiner suggests, would need, "…the courage to break with one's engineering paradigm as required and to operate pragmatically and unscientifically in the public world rather than theoretically and scientifically in the special world of engineering." (Steiner, 1998:1).

4.3 The integrated approach

The next cycle, which will be implemented for the start of the 2001 academic year includes two fully integrated subjects, one in engineering design and one in ergonomics. This model has been designed to encourage engineering and ergonomics students to join together as human centred engineers, learning with and teaching each other and their facilitators.

This model is to be a web based virtual environment which will allow the students to problem solve 'real life' challenges in a 'safe' environment. The web environment will facilitate the interaction and development of the system by use of:

- multiple threaded discussion lists - between students of the same discipline, between paired teams, between teams (that is, all enrolled students and their lecturers)
- communication of concepts to each other in the virtual environment on two levels, an artistic impression of the system and use of hot spots revealing detailed technical information
- in the virtual environment, provision of a tool box containing the tools needed (for example, the ergonomic students would have in their tool box software for calculating the manual handling load of a particular task)

- the availability of the necessary graphics packages for creating a 'user friendly' virtual environment (for example, the ergonomic students would be able to define their operators by size, ethnicity, gender to assess the impact of anthropometrical variation)
- communication on a formal level as well, for example, short technical reports

The nature of this learning environment will afford students the opportunity to learn at their own pace. At present, ergonomics and engineering distance students (at Central Queensland University) are required to complete a mandatory residential school component to acquire the practical aspects of developing and analysing design. This model has the potential to negate the need for students to attend the residential school. Anticipated outcomes are presented in terms of the learner and the curriculum.

Learner outcomes:

- enhanced information literacy skills
- improved motivation and attitudes to learning
- enhanced communication processes in a multidisciplinary team
- increased capacity as self directed learners and acceptance of responsibility for their learning
- increased critical thinking strategies and practices
- increased appreciation of the social, cultural and professional context, and application of skills, knowledge and understanding

Curriculum outcomes:

- provision of a virtual 'real world' experience in a supportive and safe environment
- improving the relevance of specific course units and programs

- enabling the development of generic skills and attributes for lifelong learning
- development of a holistic curriculum
- enhanced global understanding of the unit content

The greatest strength of this model will be to facilitate 'real life' involvement in system development, providing the learners with an opportunity to make mistakes while being supported in a safe environment. Other strengths will be the enhancement of communication processes in a multidisciplinary team, to develop and explore the processes student to student. The model will support and encourage the changing role of the lecturer to that of facilitator, and the development of student centred learning, enhancing the level of student responsibility. The experience should promote collegiality between the disciplines at student and lecturer level. It is hoped that learners and facilitators will learn with and from each other, and participants will develop a sense of 'comradeship in diversity'. This use of a systems approach to teaching and learning as a program attribute, drives the student acquisition of generic attributes identified as necessary competencies of both disciplines.

In an industrial and economic climate where competition between people, teams, departments and divisions has become the norm, problem solving abilities and opportunities have been compromised (Deming, 1993). The key to developing problem solving skills is cooperation and interdependence, working together to accomplish shared goals (Deming, 1993, Johnson, Johnson and Smith, 1998). Smith (1998) cited that multiple research has found that those who experience cooperative learning in small teams will attain benefits including: (a) higher achievement and greater productivity, (b) more caring , supportive, and committed relationships, and (c) greater psychological health, social competence, and self esteem. While the scope of this

project may not realise all of the outlined benefits, it is believed that utilising a cooperative learning framework will enhance the development of the desired generic attributes of professional engineers and ergonomic practitioners.

5. Conclusion

This study provides a preliminary review of the linkage between engineering and ergonomics education in Australia. It draws on the disparity between social responsibility and the technical reliability in the engineering design process. Following several years of pedagogical developments in the teaching of engineering design and ergonomics as allied discipline areas, this paper concludes that it is not enough to simply raise the awareness of ergonomics in the minds of engineers. This ideal, while necessary as a starting point, does not allow human centred design to occur. The responsibility for human centred design does not rest solely with the engineering profession. There is a great need to develop professionals from the fields of engineering and ergonomics who are both aware and have the skills to minimise cross disciplinary design mismatches and conflicts.

This can only be done through a change of teaching paradigm. This research suggests that the pedagogy required is multi-disciplinary teams of facilitators teaching multidisciplinary teams in a collaborative framework. The fact that this is not how undergraduate engineers and ergonomists are currently being prepared for professional practice in Australia, indicates that the paradigm shift goes beyond the undergraduate educational requirements, and encompasses the professions individually and collectively.

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