Engaging Students for Active Learning: Structuring a Project Subject for First Year Engineering Students

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Abstract: *This paper reports on how an engineering project subject was structured in line with engagement theory to provide more active learning for students to achieve the stated objectives. The design and development steps of five real world oriented projects were structured into three major phases. Students were engaged in the roles of a manager, constructor, and tester/documenter in a team in rotation that resemble the real industrial world. Relevant pedagogical theories supporting this approach were discussed. Based on an evaluative survey, this paper also presents students' feedback on the effectiveness of learning this project-based subject.*

Keywords: *Project-based learning, engagement theory, structured approach, generic attributes, learning environment, learning experience.*

Introduction

There is a greater emphasis on the introduction of project based learning across all years in the teaching of engineering courses on a worldwide basis. In the first year of the course this is a more difficult task due to the students' limited or even non-existent technical knowledge. Further, both the Institution of Engineers Australia Professional Engineering Program Accreditation document (IEAust, 1997) and the Swinburne University graduate attributes (Swinburne, 2002) encourage the introduction of this type of content delivery method in order to ensure the desired student outcomes.

The subject HET1005 – Engineering Projects was developed to address the above attributes in the first year of the Bachelor of Engineering (Electronic Engineering & Computer Systems) course with the expectation that students after completing this subject should have:

- had experience in the work of a professional engineer in a representative context, and shared in the experience of other students engaged in projects, leading to a more inclusive understanding of the engineering profession.
- an appreciation of the social context of engineering work.
- conducted at least one small engineering design project from conception to final product.

- constructed a richer understanding of fundamental concepts through active engagement with these concepts in an application to "real world" problems.
- developed problem identification and solution skills.
- further developed skills in working as part of a team.
- gained skills in accessing, interpreting and using information from a range of sources.
- improved skills in a range of communication modes.
- developed time management and organisational skills.
- developed physical skills appropriate to the project type.
- reflected on personal strengths and weaknesses, and developed a better understanding of themselves as learners and individuals.

Theoretical bases of the approach

The design of the approach to teaching this subject is based on the following educational principles:

Engaging student learning

The basic concept of engagement theory argues that, in order to motivate students, they must be meaningfully engaged in learning activities through interaction with others. Kearsley and Shneiderman (1999) suggest that students will be engaged in their learning if they are involved in active cognitive processes that involve creating, problem-solving, reasoning, decision-making and evaluation. Students will not be strongly motivated if the activities they are required to undertake only involve them in acquiring facts and accessing information. We used an approach aimed at facilitating student-centred flexible learning, in order to motivate students to learn both individually and collaboratively.

According to Anderson (2002), for engagement to occur, students not only have to work interactively with the content, but also need to work with their 'own reasoning' and 'perspective'. The aim is to develop and contribute personal insights that further enrich the understanding they and their peers acquired from class instruction or other forms of learning. Consequently, engaged students are able to make important contributions to the meaning and value of what is studied.

Project-based learning

Meaningful project work engages students to be creative, inquisitive, and collaborative. Project work is an ideal context in which to apply engagement theory. It requires students to be actively engaged in meaningful learning by sharing ideas about project activities and then to further develop what they have learnt about a topic into a product. As noted by Saiedian (1998), an early participation and exposure to group projects would also help students to understand that written and oral communication, interpersonal skills, and the ability to analyse results are important competencies of a professional in the real world. Group project work provides learning experiences whereby students not only develop skills through doing, but are also involved in deep approaches to acquire knowledge. Project work promotes student autonomy in such a way that students have to be responsible for their own learning and consequently will develop lifelong learning skills.

Project-based learning also introduces some of the practical issues that face product development teams in industry. One of the five major benefits of group project suggested by Mello (1993) is that students become more prepared for the real world. A student in a team will be able to gain an overall understanding of roles in a product development team that is difficult to obtain without the support of a group. Group projects are becoming an essential part of teaching and learning in most of engineering courses because of their relevance to industry.

Design of the learning environment

The structured approach

For project-based teaching to succeed, appropriate planning is very important. In order to achieve the expected learning outcomes considerable care has to be taken to insure that the class project is structured in such a manner that students, working together, acquire valuable knowledge and develop in them the graduate attributes demanded. For this to happen five "real world" projects were identified and well defined, each covering an important discipline in Electrical Engineering. Specifications for these projects are summarized in Table 1. Students were told why they are learning the particular disciplines and how these disciplines relate to each other. The aim was to let students understand the purposes of their project work and the cognitive processes involved.

Project Number [**Dick Smith Code**]	**Project Specification**
Project 1 (P1) [K1329 VELLEMAN Water Alarm Kit]	The *SnowWhite Washing Machine Company* is experimenting with electronic controls for their latest range of heavy-duty washing machines to be called the *Grumpy*. Your design team has been given the task of designing a "water alarm" module for this new product range.
Project 2 (P2) [K1334 VELLEMAN Sound Level Meter Kit]	The legal firm of *Bumstead & Co* (specialists in class action claims) has devised a marketing plan to inform people attending "rave parties" of the possible hearing damage that may be caused by the high noise levels within such venues. Your design team has been given the task of designing a "sound level meter" module that may be handed to potential clients for the purpose of obtaining evidence.
Project 3 (P3) [K2631 DS Wireless Microphone Kit]	The online startup venture, *Junkfoodtogo.com* wants to establish an inhouse mobile communication network for its staff of 2000 "online personal shoppers" at its purpose built warehouse complex. Your design team has been given the task of designing a self contained "Microphone – Transmitter Module" that may be used in such an application.
Project 4 (P4) [K3533 DS Clifford the Cricket Kit]	The business plan of the internet startup, *Howgreenwasmyvalley.com*, calls for the commercialisation of a range of electronic insects or e-bugs. The company hopes to obtain the support of the Green Community and list on the stock exchange as soon as any of its products become available. Your design team has been given the task of designing its flagship product an "electronic cricket" which is the first member of its *teenygreeny* range.
Project 5 (P5) [K1254 DS Formula-1 Car Kit]	The next *PetitPrix* is scheduled for Melbourne (probably along the corridors of the SE building at Swinburne University of Technology). Your design team has been given the task of preparing an entry vehicle for this forthcoming event.

Table 1: Project Specifications

Completing projects that relate to real world situations require different teaching and learning strategies. It can be daunting, if not frightening, to students who have no industrial working experience and little or no technical foundations, to expect them to solve problems connected to the outside world. For students who have work experience, it can be a little easier, as they can relate a project to a work situation that is familiar to them. To achieve this, all potential projects were screened to ensure that they are appropriate for the subject matter involved and that the scope of work is feasible within the students' knowledge base and available timeframe.

Teaching and learning details

The subject is timetabled for 36 contact hours per student in the second semester of their eight-semester long course. At this early stage of their academic path, since the technical knowledge of these first year students is assumed to be minimal, asking them to design a solution to an engineering problem from first principles would result in frustration for most. Therefore, as a compromise, after the students are guided through the research steps, we issue them with an appropriate commercial kit to carry out the project work.

The option of kits rather than loose components was selected in order to minimise any associated administrative work. Further, the kits were selected with the following criteria in mind:

- low voltage based systems (for safety);
- hardware rather than software solutions (for better understanding of circuit behaviour);
- discrete and/or SSI devices (for maximum exposure to classic components).

This approach attempts to expose all of the students to valuable hands-on activities, and accommodates, in the later stages of the project cycle, extension work for some of the more capable students.

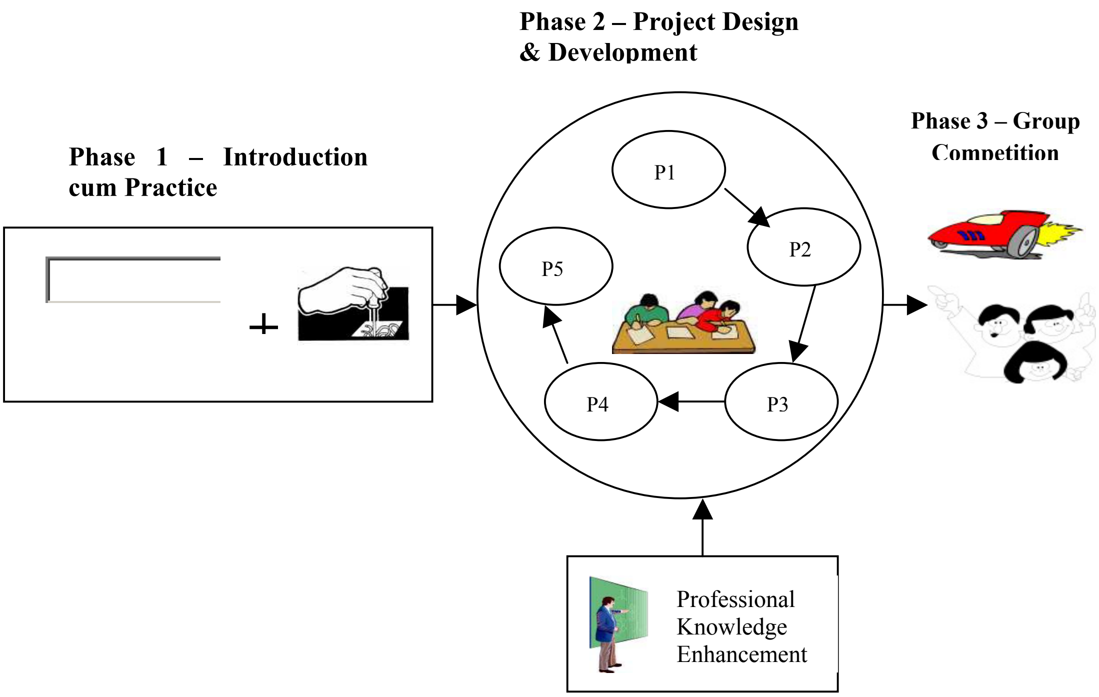


Figure 1: Project Teaching and Learning Arrangement

The teaching and learning structure of this subject is made up of three Phases, as illustrated in Figure 1 above.

Phase 1 – Introduction cum Practice

The first three contact hours are spent on discussing the engineering design process, as well as giving students the opportunity to practise using a soldering iron.

Phase 2 – Project Design and Development

In Phase 2 the students are given five small commercially available project kits, each one selected to highlight the discipline of electronics, instrumentation, communication, microcontrollers and/or machines. Table 1 shows the specifications of these projects.

Under staff supervision and guidance, the projects are completed in six contact hour cycles (a total of thirty hours) during which the students carry out some research, construction, testing, documentation and then discuss component operation (a macroscopic view), commercialisation and possible improvements to the design. One of the remaining contact hours is spent enhancing students' professional knowledge by focussing on discussing professional issues such as IP protection, entrepreneurship, the role of professional societies and venture capitalists.

Phase 3 – Group Competition

During the final two contact hours the students are given the opportunity to fine tune their last project (a model F1 racing car) and then race it against others in the MiniPrix held along the corridors of one of the on-campus buildings.

Group activity

To facilitate the students' learning of teaming skills and to monitor the ongoing quality of team processes, as suggested by Lewis et al (1998), the students are divided into groups of three. For each project, the roles of manager, constructor and tester/documenter are rotated so that each student spends approximately the same effort in the last two roles. This is possible because the complexities of each of the chosen projects are of a different level. Each student is required to keep a detailed logbook that is assessed at the end of the semester. Each group must deliver a seminar presentation and a formal report on one of the projects that was randomly assigned by the staff member.

Have the expected learning outcomes been achieved?

In order to gain some understanding of whether the learning objectives have been achieved, a survey was used (with Ethics Committee permission) in order to solicit students' feedback on various aspects of the teaching and learning process. Students' final scores were also reviewed in order to gauge the success of the Subject.

Student Feedback

The survey questionnaire consisted of Likert statements and open-ended questions on factors of 'Objectives and Educational Value', 'Structure of Subject', 'Facility and Resources', and 'Assessment of Subject'. The survey was administered to all 25 students enrolled in the subject after they delivered their respective seminar presentations. Table 2 below summarizes the responses obtained.

Legend:
SA=Strongly Agree, A=Agree, N=Neutral, DA=Disagree, SD=Strongly Disagree

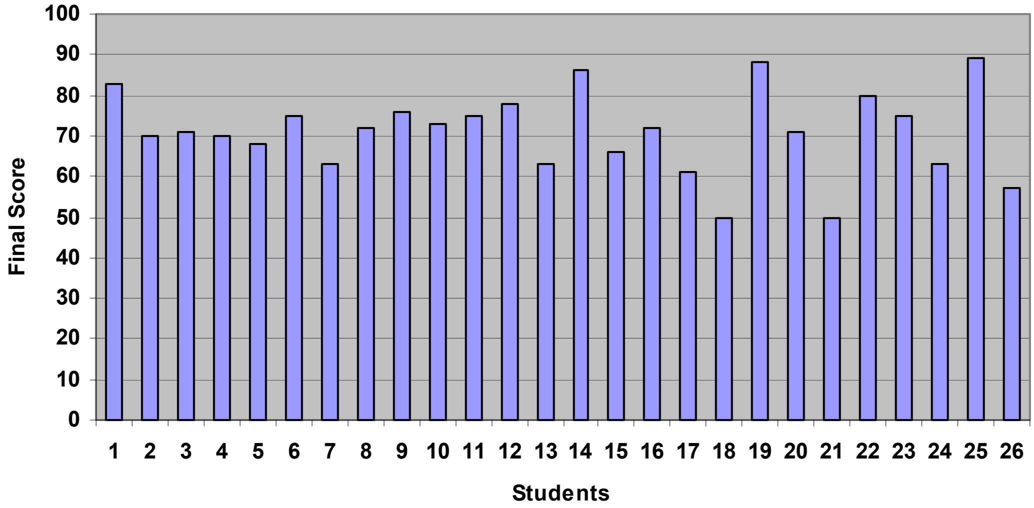
	SA %	A %	N %	DA %	SD %
Objectives and Educational Value					
In competing the projects I have developed professional skills in the field of engineering.	16	76	8	0	0
I could see the relevance of the projects to the field of engineering.	32	56	4	8	0
I have been presented with real world engineering problems to solve.	8	68	12	12	0
I felt encouraged to produce a number of ideas.	4	72	24	0	0
I have developed efficient problem solving strategies in completing the projects.	16	48	32	4	0
I have developed the ability to solve real problems in the field.	4	60	24	12	0
In completing the projects with other members I have developed different forms of verbal and non-verbal communication skills.	24	64	8	4	0
I thought the Subject has provided valuable learning experiences in the work of a professional engineer.	28	60	12	0	0
Structure of Subject					
I received sufficient guidance in structuring the project design process.	20	64	16	0	0
There was ample opportunity for questions and discussion during project sessions.	28	64	8	0	0
The class involved useful group sessions where we can talk about our work.	32	52	16	0	0
I felt that the teaching strategies were compatible with the Subject objectives.	16	64	20	0	0
Facility and Resources					
Equipment and supplies for the projects were readily accessible.	28	60	12	0	0
Equipment and facilities for the projects were in good working order.	24	60	16	0	0
Reference materials for this Subject were readily accessible.	16	52	32	0	0
Assessment of Subject					
The workload was appropriate for the credit point value of the Subject.	12	72	12	4	0
There was a balance of emphasis between the report and end product being assessed.	8	76	16	0	0
I have had enough opportunity to demonstrate what I have learned in this Subject.	12	80	8	0	0

Table 2: Student Feedback

Students in general agreed that this subject has provided them with learning experiences that facilitated them to achieve the stipulated objectives. They felt that they have developed in themselves some of the graduate attributes required to enter the world of professional engineers. Students also agreed the subject was well structured in that they have been provided with sufficient guidance in the design and development of the projects and engaged in various meaningful group activities. The survey results also revealed that students were satisfied with the facility and resources available to them in completing their projects. With regard to the assessment process, students agreed that they have been given a fair chance to demonstrate what they have learned in a balanced manner emphasising both the process and product.

Student Performance

Students were assessed in both the process of solving the problems posed in the projects and the outcome. Students had to submit a logbook and project reports for assessment of the process. In order to assess the outcome, groups were required to make presentations on their project work to the class, during which the students were given the opportunity to assess their peers as well. Assessment weightings allocated to each of the components were logbook – 40%, formal report – 30%, seminar presentation – 20% and peer assessment – 10%.



mean = 71, standard deviation = 10

Figure 2: Consolidated Class Results

It can be seen from Figure 2 that the students, in general, achieved good results with a mean score of 71.

Conclusion

The idea of using a structured approach in project-based teaching in order to engage students in their learning has been very successful in this case. Students' feedback and their actual performance indicated that the learning experiences created were successful in engaging students in meaningful group activities, in order to achieve the stipulated objectives. We believe the success of project-based teaching, in the first year of Engineering courses, relies on the academic acknowledging the possible limitations in the students' technical knowledge by selecting projects that expose the student to simple basics (such as discrete components discussed functionally rather than operationally) instead of more technically appropriate but also more complex alternatives (for example, VLSI and LSI based solutions such as microcontrollers or other custom chips that can only be treated either in too much detail or as "black boxes"). Further, the academic must ensure that the students understand not only the tasks they are to undertake, but also the purposes for such activities. Finally, from an administrative viewpoint the subject was found to be scalable as long as the staff-student ratio was maintained.

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Acknowledgement

The authors would like to acknowledge the constructive suggestions and criticisms offered by Dr. Margaret M Mazzolini, Swinburne University of Technology, Melbourne, Australia.

Cultivating generic capabilities to develop future engineers: an examination of 1st year interdisciplinary engineering projects at the University of Sydney

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Abstract: *Looking towards the future it was commented in 1994 that 'the professional engineer of the 21st century will require a degree of flexibility and a technical skills base difficult to imagine at this time. The educational system must be responsive to that need' (Abdallah & Hood, 1994, p. 55). From this response has emerged a collection of generic attributes and capabilities that are desired of graduates upon completion of their undergraduate engineering degrees. This paper examines some of the ways in which the Advanced Engineering Program at the University of Sydney and particularly the Interdisciplinary Projects undertaken in 1st Year foster some of these attributes early in the university experience of high achieving students. The program offers engagement with different research groups, opportunities to develop teamwork, management and communication skills and the promotion of innovation and creativity within the interdisciplinary context, and thereby identifies a vision that could be applied to other undergraduate engineering courses in Australia.*

Keywords: *innovative engineering education, generic capabilities, interdisciplinary projects*

The Changing Face of Engineering Education

With the emergence of a global economy in the late 1980s, it became imperative that Australia increase its international competitiveness. In turn, the quality and nature of the nation's educational and training programs was scrutinised, particularly those in the higher education sector. In addition, the rapid acceptance of and demand for high technology by society in the past decade and the changing nature of the workplace as a result were further catalysts to educational change. The Finn Report (1989) recommended a convergence of general and vocational education and established targets for student participation in education and training following the compulsory years of schooling. In addition, the Mayer Report (1992) on the place of key competencies in education and training was a key formative force and resulted in several reviews of engineering education in subsequent years. The acceptance of the seven key competencies now provides a nationally recognised framework for all levels of education across Australia. These competencies are as follows:

- Collecting, analysing and organising information
- Communicating ideas and information
- Planning and organising activities
- Working with others and in teams
- Using mathematical ideas and techniques
- Solving problems
- Using technology

For engineering education, another contributing factor was the signing, in 1989, of the Washington Accord by the main accreditation body in Australia, the Institution of Engineers, Australia (IEAust), which resulted in moves to bring accredited engineering degree programs in line with international standards. This multinational agreement recognises 'the substantial equivalency of accreditation systems of organizations holding signatory status, and the engineering education programs accredited by them' (The Washington Accord, 2002). Given these frameworks and prompted by the changing aspects of the environment, in which engineering was practiced and in the profession itself, a major review of Australian engineering education occurred in 1994. The resulting report, *Changing the Culture: Engineering Education into the Future*, proposed that most engineers should complete 'a broadly based undergraduate course' and should seek to be 'knowledge navigators able to access, analyse and apply relevant information from any source' (The Institution of Engineers, Australia, 1996, p. 15). There is an obvious reference to the key competencies mentioned above.

The report also outlined the key characteristics that engineers must display to and for the benefit of the community. Professional engineers of the future must have a 'high professional and ethical standard', 'a sense of social, ethical, political and human responsibility' and be 'aware of the social and environmental implications of their work' (The Institution of Engineers, Australia, 1996, p. 88). A desire amongst engineering graduates for lifelong learning accompanied by a passion for change and critical thinking were also identified as ways to keep up with the ever-changing pace of the engineering profession. Contributors to the *Changing the Culture: Engineering Education into the Future* report identified and envisaged graduate engineers as individuals with 'a creative spirit, a capacity for critical judgement, and enthusiasm for learning,' with the willingness to 'initiate and participate in change,' and are those who participate in 'a culture of life long learning' (The Institution of Engineers, Australia, 1996, p. 89). Engineering faculties in Australian Universities have embraced the report to varying degrees, with general acceptance of the need for these attributes in graduate engineers.

Generic Attributes for Engineers

Following these reviews and in consultation with industry, government, educational institutions and the wider community IEAust produced the *Manual for the Accreditation of Professional Engineering Programs* in 1999. This document is the basis by which IEAust accredits engineering degree programs offered by Universities and aims to simulate innovation and diversity, maintain standards and put in place policies to overcome some of the hurdles identified in engineering education to date. The central framework of this document is based on the seven key competencies and is extended to the engineering discipline where appropriate. As stated in this document, graduates of accredited programs should have the following generic attributes:

- ability to apply knowledge of basic sciences and engineering fundamentals;
- ability to communicate effectively, not only with engineers but also with the community at large;
- in-depth technical competence in at least one engineering discipline;
- ability to undertake problem identification, formulation and solution;
- ability to utilise a systems approach to design and operational performance;
- ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member;
- understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development;
- understanding of the principles of sustainable design and development;
- understanding of professional and ethical responsibilities and commitment to them; and
- expectation of the need to undertake lifelong learning, and the capacity to do so.

Of particular note in this document is the recognition of the need for undergraduate programs to further develop the communication, teamwork and leadership skills that make for valuable and high achieving graduates.

Recent Insights into Engineering Education

In the years following the specification of the generic attributes for engineers and the major reviews of engineering education, many universities have taken steps to modernise their course structures and content. In many instances, this has lead to the inclusion of project based and experiential subjects in courses, as well as greater emphasis on these concepts in existing subjects. Also, of particular interest, is the recent recognition of 'emotional intelligence' and its social aspects being of high importance amongst recent graduates in their practice as professional engineers. Sentiments drawn from the opinions of high achieving graduates from the University of Technology, Sydney (UTS) in the few years after graduation outlined in the report *'Using Successful Graduates to Improve the Quality of Undergraduate Engineering Programs'* (Scott & Yates, 2002) highlighted some of the capabilities that are seen to be of most importance in professional practice. The study concluded that 'the combination of emotional intelligence, a focused and contingent way of thinking, a specific set of generic skills as well as technical expertise accounts for the successful delivery of engineering projects to specification and high levels of client and employer satisfaction'.

These factors and insights along with the promotion of engineers as an 'interpreter as well as a practitioner of technology' (The Institution of Engineers, Australia, 1999, p. 9) has lead to course structures that focus upon the 'capacity to grapple with ill-defined and broadly-based problems.' The paradigm has shifted, in engineering education, to the application of sound methods and solutions to broadly based problems, without negating the need for the traditional imparting of scientific and technical knowledge. Fulfilling this objective has not been straightforward with many programs searching for a satisfactory balance between content and competency based courses.

A Case Study: 1st Year Interdisciplinary Engineering Projects

In 1998 the Faculty of Engineering at the University of Sydney initiated a unique and innovative program to enliven the learning experience of its high performing school leavers. Students, who have proven their outstanding academic capacity in their HSC by achieving a UAI higher than 98, are invited to participate in the Advanced Engineering program in 1st semester instead of taking the normal mathematics and physics subjects. This generally equates to 30-40 students who are eligible each year for the program, yet not all choose to participate. The program is equivalent to half of the students' Semester 1 studies and all are expected to catch up, where applicable, on the scientific content missed in their own time. Students are presented with a variety of design concepts or problems and, based upon their project preference, are placed in groups of 5 or 6 under the supervision of an academic or mentor with an interest in the project. Each project is unique, having never been undertaken before.

In preparation for spending the semester working together and in view of the nature of projects they will be completing, students undertake several workshops in teamwork and group skills, project design and management and intellectual property issues. Students spend the remainder of the semester meeting in their project teams, taking their concept from an idea to a working prototype. Along the way, each group prepares a detailed project specification, presents two progress presentations and produces a final report. The program culminates in the display and demonstration of a working prototype at the University's Courses and Careers Day. Assessment is made up of components for the report, presentations, demonstration and participation. The latter goes beyond purely a mark for attendance, by evaluating the student's overall contribution and commitment to completion of the project. Students also frankly and confidentially assess their peers' performance throughout the semester. To accommodate personal biases and differences, this evaluation is then compared with and considered in light of the supervisor's comments.

Engagement with Industry & Research Groups

The involvement of a variety of different groups in the 1st Year Interdisciplinary Projects has added to and enlivened the students' overall learning experience. In previous years, research groups from within the University including those from other faculties, such as the Ocean Technology Group in the Department of Civil Engineering, the School of Mathematics in the Faculty of Science and the Rehabilitation Research Centre in the Faculty of Health Sciences, affiliated organisations such as the Australian Centre for Field Robotics and external organisations and industry groups including Esso Australia, Photowatt Laboratorie, Swann Communications and Mars Society Australia have contributed to the program. These groups along with the Faculty's academics have provided project impetus in stimulating and cutting-edge areas, sources of supervisors and information, access to facilities and other resources and most importantly for students, interaction with a diverse group of professionals modelling engineering best practice.

Furthermore, students have been able to see the impact of their efforts in real situations just as they would in the workforce. For example, the Rehabilitation Research Centre at the Cumberland Campus of the University has partnered with several teams of students involved in the program and a lecturer from the School of Aerospace, Mechanical and Mechatronic Engineering over the past few years to further develop components of a new exercise bike technology known as Functional Electrical Stimulation (FES) that aids in the muscular development of people with spinal cord injuries. Given the real-life nature of this project and others, students are engaged in worthwhile endeavours that heighten their learning experience. Such links across engineering schools, with different faculties, industry and specialist research groups, is also of benefit to the Engineering Faculty as it adds to the learning experiences of all its students and provides opportunities for the future.

Students are also exposed to the nature of research within a University environment, including working with some world leaders in their given field. This experience is likely to prove beneficial to students in later years as they consider thesis projects and possible postgraduate studies. It remains to be seen whether this program will have an effect on the number of students who engage in such programs. It can be expected that the future involvement of these students, will be beneficial to the research groups of the University in the coming years.

Applying Knowledge & Management Skills in a Teamwork Environment

In most instances, students work on projects that are in areas they have not encountered before. Team members are required to research and analyse the issues relevant to their design brief. Given the interdisciplinary nature of the teams (students are drawn from all engineering disciplines offered by the Faculty) students become aware of their own unique skills and abilities and the value they bring to a team working together towards a common goal. This represents the ever-increasing interdisciplinary nature of engineering practice that students will encounter upon graduation.

Under the guidance of their supervisor, each team establishes a timeline for the development of their project. There is the expectation that groups with self-chosen goals will ‘necessitate the discovery of relevant knowledge, flexibility of thought, the suspension of judgement, and integrated and creative learning’ (Gregory, 1972, p. 142). Focus groups with students during and at the completion of the program found that this has certainly been the experience of students involved to date and has been integral to group success in the diverse projects undertaken.

One of the key competencies outlined in the Mayer Report (1992) calls for the capacity to plan and organise activities. Once the project team has established the timeline and goals, students are encouraged to manage the tasks they have been assigned, as well as utilise their time and resources efficiently for the collective benefit of the group. Such experience provides a useful introduction to project management and advocates each participant’s effective function as an individual and team member. A workshop session on Project Design and Management adds to this palette of skills and knowledge, as a professional engineer engaged in employment in industry informs students of the latest management techniques that will assist them throughout the course of their project’s life and beyond.

Teamwork goes beyond purely individual skills. By engaging within a team, not only do students discover insights into their own unique skills, they also gain a greater understanding of the skills of others in the group. Hence, they learn not only the value and place of their individual talents, but also how the whole team can work together with different skills to achieve a collective purpose. Throughout the course of developing their projects, students will inevitably be presented with situations where they must come to terms with the limitations of their own capacity as an individual, and in turn realise the need of others to work effectively.

Developing Communication Skills in the Interdisciplinary Context

Engineers have frequently been criticised for their poor communication skills. Comments made by industry and the wider community during major reviews of engineering education in Australia have highlighted this serious deficiency. When asked what functions engineers must provide for the community in 2010, it was seen that there was a need for graduates to leave university with the ability to 'identify, access, organise, and communicate leadership in both written and oral English' (The Institution of Engineers, Australia, 1996, p. 87). This argument was strengthened further with statements, among others, desiring engineers who can 'communicate clearly and fluently in writing' and who are 'self-confident and orally articulate' (The Institution of Engineers, Australia, 1996, p. 87).

The forms of assessment used in the 1st Year Interdisciplinary Projects and the continual demands of working in a closely-knit team draw out and further develop the communication skills of students enrolled in the program. Students must present two seminars to report on the progress of their project; one mid-way through the program and the other as it draws to a close. Furthermore, in some years, students have given formal presentations to the general public as well as manning a display of their projects during the University's Courses and Careers Day. This has proved a very effective means for students to practice communicating with those not familiar with their projects and also those not accustomed to the 'language' of engineering. These experiences are in line with the need to be able to 'communicate effectively, not only with engineers but also with the community at large', which is recognised as a generic attribute required of an engineering graduate in the *Manual for the Accreditation of Professional Engineering Programs* (The Institution of Engineers, Australia, 1999, p. 5).

The 1st Year Interdisciplinary Projects provides a good introduction to working in project teams similar to those in industry, as do the progress seminars each team must present. Displaying similarities to business presentations, and employing the same skills and professionalism; these seminars are a unique and worthwhile experience, uncommon in the early years of an undergraduate engineering program. The final project report permits students to demonstrate their understanding of the engineering concepts and communicate their project's results and outcomes in a written form. Calling for a critical assessment of the successes and failures of the group's final product and indications of future directions for the project, the report adds to the ways in which the assessment structure encourages students to develop communication skills.

Participants in the program, aside from having proven academic ability, are from all engineering disciplines, and have a variety of different cultural and ethnic backgrounds; as the program attracts some international students, hence differing educational experiences. To enable a project team to complete their stated goals, they must overcome to some degree communication hurdles as well as accommodate differences in learning, interests and previous experience. Working in a small group changes the dynamic of team meetings, planning sessions and discussions, where more dominant personalities and other features of personalities can emerge. To prevent an individual's display of leadership, enthusiasm and initiative turning into dictatorial, overbearing and destructive patterns, effective communication is required. Instances in which a confident individual may dominate the discussion during the first progress seminar have been observed but interestingly, such events have not been as obvious during the final seminar presentation or discussions with groups at the Courses and Careers days, which suggests that students have developed; whether it be in their confidence with the material they are presenting or the manner in which they are presenting it. Perhaps some form of teamwork assessment instrument could be given prior to, during and at the end of the course, to assess and map the changes in student capabilities to manage these situations.

Promoting Innovation

Innovation is best described as 'a process of turning an opportunity into new ideas and of putting these into practice' (Tidd, et al, 2001, p. 42) and is closely linked with the ideas of design and creativity. Many examples can be seen amongst the outcomes of and processes engaged in during the 1st Year Interdisciplinary Project. It has been noted by Gregory (1972, p. 143) that 'over the whole engineering range, from education to practice, there is a need to abandon those defensive positions so readily adopted, and open up not merely to enquiry but to outgoing findings', and thus promoting innovation and creativity amongst engineering undergraduate courses is a valuable endeavour. Such an activity must increase the engagement of students in their studies and adds to the level of enjoyment experienced as they overcome the 'constraints of convergent thinking and rigid analysis' (Gregory, 1972, p. 143) historically associated with engineering studies at university.

In December 1996, the National Review of Engineering recommended that IEAust in close collaboration with the Australian Council of Engineering Deans (ACED) developed a new accreditation system for engineering schools that 'stimulates innovation, experimentation, diversity and quality assurance both in programs and their delivery' (The Institution of Engineers, Australia, 1999, p. 8). Many elements of the program, from the conception of an idea through to its implementation, call for creativity and innovative thinking and approaches, from using techniques such as 'brain-storming' and 'mind-mapping' to finding unconventional methods to solve problems. One group, after much frustration in the pursuit of a professional process for moulding plastics to a given specification, created a mould for themselves using plaster and proceeded to mold the plastic shape required in a conventional kitchen oven, albeit with little success. Such ingenuity and the freedom to explore ideas throughout the design process is extremely attractive to students fresh to the university experience and is a highlight of the whole Advanced Engineering Program at the University of Sydney.

In the formal sense, instances of innovation have been recognised by patent applications for the outcomes of several projects. These have included a unique wind powered dolphin-tail propulsion system for a yacht known as a dolphin propulsor and a hand powered vehicle that is ergonomically efficient and allows paraplegics to attain the speed and efficiency of a bicycle. The workshop conducted by the Business Liaison Officer from the University on Intellectual Property Issues in the first weeks of the program gives a foretaste of the possibilities the students have before them with their projects and adds to their enthusiasm. It also provides an important background to the legal issues associated with innovation and particularly patents, which is probably lacking from most engineering graduate's knowledge.

Overcoming the Barriers

One of the major concerns to date with regards to the 1st Year Interdisciplinary Projects is the effect it has upon students' other subjects. By participating in the program, students are exempt from the basic maths and physics/chemistry usually studied in first semester. For some students, this is a great privilege, and provides the freedom to explore more interesting applications of their studies, such as those examined in the project. For other students, however, this may potentially have a detrimental effect on their performance in later subjects where understanding of these fundamental subjects is drawn upon and expanded. Some fears were overcome in the earlier years of the program when it was found that nearly all of the students who participated were on the Dean's list at the end of their first year of study. All students have managed to perform well in later years Science subjects and the scheme is seen to be giving students responsibility for their own learning.

As a high mark in the HSC or similar high school assessment may not guarantee high performance in university study, it has been suggested that the Faculty evaluate a student's prior knowledge of the material that would be covered in any subjects missed. Rather than becoming an entrance test or similar for the Advanced Program, it could serve as a good indicator of additional assistance that students require so as not to hinder their performance in future years. The program is currently being changed so that Advanced Engineering students will have more freedom in choosing which subjects are substituted in their 1st semester in line with their strengths and weaknesses. Having said this, the skills and abilities developed throughout the program should help equip these high achieving students to overcome some of the barriers they may encounter in later years.

Several barriers exist which inhibit the program being expanded to a larger number of students. Among these, a shortage of staff to act as project supervisors and limited resources and funds available to invest in the individual projects, are the biggest hurdles. The capacity of students who do not fulfil the current entry criteria (i.e. UAI > 98) to handle missing particular fundamental units of study must be considered further before any expansion takes place. Furthermore, the uniqueness of the program may be the key to its success to date. Yet the vision the Advanced Engineering Program encapsulates is one that will ultimately benefit Australia's future engineers and the nature of engineering education if applied to a broader cohort.

Conclusion

Through its involvement with industry and research groups and the manner in which teamwork, management and communication skills are developed, the 1st Year Interdisciplinary Projects are paving the way forward in engineering education by cultivating the generic attributes that industry and the community will demand of the engineers of tomorrow. By modelling the interdisciplinary nature of professional engineering practice and inspiring innovation, critical thinking and creativity, the program is adding to the learning experience of its participants and equipping them for their future studies and beyond. Foundations are being laid that will allow future graduates to apply sound methods and solutions to broadly based problems within the framework of the required scientific and technical knowledge. In forming a vision for the future of engineering education, opportunities exist to further research the impact of the Interdisciplinary Project on the skill development of graduating engineering students and to track their career success and other's perception of the Project's contribution to that success. Extending the program to involve more students in the future (possibly by lowering the entry requirement) may be a significant development that could be implemented across the entire undergraduate engineering cohort. The 1st Year Interdisciplinary Engineering Projects at the University of Sydney are providing a flexible innovation in engineering education and the development of Australia's future engineers through the focus on engagement with research and industry groups, generic capabilities, communication and teamwork.

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A continuous improvement strategy for undergraduate teaching in higher education

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***Abstract**: This paper discusses a continuous improvement strategy drawing heavily on video and multi-media technology. The first step in the strategy is the routine video-taping of lectures from media-equipped lecture theatres (MELTs). Once these lectures are video-taped and digitized, they can be distributed to students via the web and CDs. Moreover, the videos give the lecturer the opportunity to watch his/her own presentations. It can be particularly effective for the lecturer to view the videos just before the corresponding class is to be given again the following year. This viewing serves as very useful preparation and enables the lecturer to see what can be improved from last year. Re-recording of the lecture incorporating these improvements enables a cycle of "continuous improvement" to be achieved. The strategy is currently in use by the author at QUT and is proving very successful.*

***Keywords**: videos, multi-media, continuous improvement*

Introduction

A number of studies have been conducted to see if students learn as well from videos as they do from live lectures. The studies have shown that students actually learn better from videos (eg. Stone, (1987) and Walker and Donaldson (1989)). This is possibly because they can watch the videos at their own pace and review material as often as they want. Additionally videos cater to students who learn effectively from either audio or visual cues [3]. Given the effectiveness of video based learning, it would be convenient if one could devise a continuous improvement strategy which involves videos, and possibly other multimedia technology such as the internet and CDs. This paper proposes such a strategy. Early feedback indicates that the strategy is very effective.

The Continuous improvement strategy

The strategy proposed in this paper is a multi-stage strategy, with the essence of each of the stages being detailed in the following sub-sections.

Stage 1: "On-the-fly" video recording of lectures

Many lecture theatres in higher educational institutes throughout Australia are equipped with video projection facilities. That is, the visual content of a computer screen or of a document camera can be projected onto a large screen so that the students can see it. It is a simple matter to connect the output from such a projection system to a video camera input and effectively "record the lecture live". (The audio connection to the video camera can be obtained either directly from one of the lecture theatre output terminals, or by using a simple conventional tape-recorder and extracting the "line out" connection while the tape recorder plays in the record mode). The set-up and recording is such a simple procedure that it can be done by the lecturer at the start of each lecture. The lecturer need only be equipped with a video camera (complete with the camera's audio-visual connection lead) and possibly an audio tape recorder. Some brief instructional training on setting would probably be needed also.

The recording of the lecture can, of course, also be done by recruiting a professional cameraman, but at much greater cost. The procedure described in the previous paragraph can be done very cheaply – only a video camera and possibly an audio tape recorder are required. Many schools and departments in higher educational institutions have these available for loan already, or can purchase them quickly. Because of the low cost of this "self-recording" option, the lecturer can choose to tape every lecture they give. Furthermore, the decision over what is recorded is much more firmly under the lecturer's control with self-recording. He/she can start or stop the recording at any time with a press of a button on the video camera. He/she can even record some clips of his/her face by doing a quick swivel of the document camera.

Stage 2: Digitisation and compression of lecture videos

Modern technology has finally moved to the stage where video capture and compression is trivial and fast. All that is required is a "firewire" capture card costing about $60, and an operating system such as Windows XP. Many personal computers are routinely equipped with this type of card and operating system. The "Windows Moviemaker" software resident in Windows XP can be used to capture and compress videos, and if necessary edit them. The time to realize the capture and compression of a video (assuming no editing is required) is often only marginally more than the time to play the video tape through to completion.

The size of the compressed video files will vary depending on their length and quality. If the "Medium Quality" option in Windows Moviemaker is used then a one hour video would occupy about 50Mbytes of disk space. The "Medium Quality" option is adequate provided that there is not a lot of fast moving detail in the video. If the Medium Quality option is found to be unsatisfactory then the "High Quality" option can be used. With such an option a one hour video would be about 100Mbytes in size.

Stage 3: Distribution of compressed video lectures to students

Once the videos are compressed they can be exported to the web and/or CDs very quickly. A streaming server will be required for web access, but many higher educational institutes now have these set up. Because of the fairly high bit rates used to build the video files the students cannot watch them from a 56Kb/s modem. Effective viewing requires either a suitable local area network or a modem with a bit rate in excess of 256Kb/s.

CDs can also be burned quite quickly and made available to students for either an overnight or three hour loan. This loan enables students to copy the CD; once students have a copy they can burn copies for friends and so distribution can be achieved quite rapidly.

Stage 4: Obtain student feedback and edit videos

In any continuous improvement strategy for teaching and learning it is imperative to obtain student feedback. Much of this feedback can be informal, but it is also good to have organized surveys to find out 1) how well the process of video production and distribution was received, 2) if there were any errors in the videos, 3) any suggestions on possible improvements. The informal student feedback can be obtained throughout the semester, but the formal surveying should be done either just before or just after exams.

Clearly, if any errors are found, the videos need to be edited before making them available to next year's students.

Stage 5: Prepare for the current year's classes by watching the videos from the previous year

All good teaching requires thorough preparation. One very effective way to prepare for classes is to watch the lecture videos made the previous year. This has two benefits. Firstly, it enables a quick way to revue the material which needs to be covered and to reconsider the way that the material should be presented. Secondly, it provides an invaluable opportunity to see how well one's explanations come across. That is, it gives the lecturer an opportunity to see the lecture the way the students would have seen it.

Repeat the cycle from Stage 1

After having watched the videos of the previous year's lectures, one is likely to have many ideas about what worked well and what did not. The new lectures are delivered with the necessary improvements.

Evaluation of the strategy

Student feedback

The strategy outlined in Section 2 is currently being trialled in the area of "Digital System Design" in the School of Electrical and Electronic Systems Engineering at QUT. The author is presently taking this subject for the second consecutive year (this year being 2003). The lectures from 2002 were all recorded as per the strategy of Section 2. During the first year of lecturing this subject there was *no* positive written feedback from students. On the contrary, there were two formal complaints to the "Staff Student Liaison Committee". There were also several informal complaints made to the lecturer. The lecture videos were modified in accordance with the complaints received. These videos are now being used to assist with lecture preparation, and as a starting point for creating new/revised videos. The feedback so far has revealed astonishing improvements when compared to last year. Two very positive emails have been spontaneously sent by students, commenting on the quality of the lecture presentations. A number of other positive comments have also been made by students, making particular reference to the benefits of having well organized videos to assist them in their study. A standard QUT "Student Evaluation of Teaching (SET)" survey was conducted recently. (The survey questions can be found at https://www.talss.qut.edu.au/talss/STAFFONLINEGUIDES/gen/index.cfm?fa=displayPage&rNum=17094). 24% of students rated the overall lecturing to be very good, 54% rated it as good, 16% viewed it as satisfactory, while 5% rated it as poor. None considered it to be very poor. Unfortunately the spontaneous written comments from students are not yet available. When they become available it will be interesting to see how many of them comment on the usefulness of the videos.

Personal reflections

The author has found the proposed strategy to be remarkably helpful. Preparation is greatly enhanced by watching last year's videos. Watching one's own presentations is also very revealing; many flaws in the delivery become immediately apparent, and provide a strong motivation for improvement. Making lecture CDs available to the students has been very much appreciated by the students and appears to be increasing their comprehension.

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Teaching and Learning Collaboration Between the ATN Universities: A Case Study

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Abstract: *This paper describes an undergraduate teaching collaboration between two academics at two different ATN universities. This collaboration has been assisted by increasing attitudes of collaboration within the ATN network and by improving multi-media technology. While the collaboration has not been in place long, early feedback indicates that it is providing significant benefits.*

Keywords: *videos, multi-media, collaboration*

Introduction

Collaboration in the realm of research is comparatively well established in Australia. It has grown substantially in the past decade because of the large financial rewards available through such things as "Collaborative Research Centers (CRCs)". In the area of teaching and learning (T&L), however, the financial rewards for collaboration have been far less apparent.

Recently, it has recognized been by the ATN universities that collaborations in *all* areas could have significant benefits [1]. This has borne fruit in new open-ness to co-operation and to the sharing of resources, particularly in the area of teaching and learning. This paper reports on one T&L collaboration between staff members at two ATN universities. These universities are RMIT and QUT, and the collaboration is in the teaching of Signal Processing subjects.

The Collaboration

Teaching and Learning collaboration between universities is often complicated by difficulties with intellectual property issues. In the Engineering Faculties of RMIT and QUT, however, in principle agreement has been obtained for the sharing of educational resources. While this has not been formalized in a written agreement yet, the verbal agreement has made collaboration smoother.

Sections 2.1-2.3 below report on a collaboration in the teaching of undergraduate signal processing subjects. It is important to point out, however, that this is only one of a number of such collaborations. There is also, for example, some joint effort at RMIT and QUT in the area of electrical and electronic circuits for first year.

Key attributes for quality course delivery

Based on student surveys conducted at RMIT, there are a number of key attributes of course units which are sought by undergraduates [2]. These are:

a) Comprehensive, well presented notes.
b) Lecture presentations which are easy to follow and which make appropriate use of technology.
c) Clear explanations in the lectures of how the theory is used in applications.
d) Permanent records of the course content in a variety of media.
e) Helpful and accessible lecturing staff.
f) Humorous lectures.
g) Good subject organization.

To truly develop all of these attributes for a course is very difficult. A wide range of skills is required and it is very unusual for one person to be in possession of all these skills. Collaboration is an obvious way to build up all these required facets.

This paper reports on a collaboration between Peter O'Shea (Collaborator 1, from QUT) and Zahir Hussain (Collaborator 2, from RMIT) for the teaching of signal processing subjects. The collaboration was a natural one, since O'Shea and Hussain were already working on joint research projects and shared post-graduate students. They had also worked together for a brief time at RMIT. O'Shea taught the signal processing subjects at RMIT prior to 2001, while Hussain has been teaching these subjects since 2001. The two therefore already had well established lines of communication. It was also a natural collaboration in that the two participants had complementary gifts and dispositions. O'Shea had experience with multi-media production and a natural disposition towards conceptual explanations, while Hussain had un-supressable humour and a focus on rigor and detail.

Contributions by Collaborator 1

The particular focus of Collaborator 1's efforts was on attributes b), c) and d) from Section 2.1. He developed an extensive suite of multi-media materials to assist with comprehension of important signal processing subjects. These are described below.

VHS Videos of lectures and tutorial sessions were placed in the library where students could watch them "in-situ". VHS videos were also placed in the design store so that students could borrow them over-night and make their own copies. The videos were found to be very effective in helping students to learn, a fact which was in line with the research findings in [3] and [4]. Some, but not all of these videos were also digitized, compressed and burned to CDs. Some were also placed on the library's Video on Demand system. Videos were also created to help students review the necessary background theory before they undertook laboratories. These videos were digitized and placed on the local area network; students were required to watch them as part of the preparation for the laboratories. A number of computer based animations were also developed so that students could visualise important signal processing functions.

The emphasis on all these materials was on explaining concepts and on the link between theory and practice. The rationale for this approach was that Signal Processing is a difficult subject area and many students need good conceptual explanations to maintain their motivation. Many of the video lectures began with a practical example to illustrate how signal processing is used in important practical applications such as radar, sonar, surround sound, speech recognition, digital video cameras, etc.

These materials were thoroughly tested and refined until student feedback indicated that they were effective in teaching the basics of signal processing. While it was pleasing to know that all students could use these materials to grasp the basics, it was of some concern that the materials were not in sufficient depth to be able to prepare the students for tackling very difficult tasks. This deeper probing was facilitated by the efforts of Collaborator 2, as described in the following sub-section.

Contributions by Collaborator 2

The particular emphasis of Collaborator 2's efforts was on the attributes not covered by his collaborator. He developed much more comprehensive and detailed notes than were created by Collaborator 1. These notes were designed to take students to a deeper level. Extensive tutorials were also developed to support these materials. The tutorial and lecture material were tested on students and initial feedback was used to bring some refinement to them.

Motivated by student feedback, several topics were developed around applications. These topics included phase locked loops, mobile communications, etc. Collaborator 2 also injected a substantial component of humour into his delivery.

Evaluation

This year (2003) is the first in which students have had access to the range of collaborative components detailed in Section 2. The signal processing subjects at RMIT are currently being taught by Collaborator 2, but students are advised that they can also access the multi-media materials developed by Collaborator 1. The latter is not currently teaching the signal processing subjects at QUT, but moves are under way to make the resources available at QUT in the same way that they are at RMIT.

Early evaluations have been mostly positive. An independent survey was conducted by the Director of Teaching and Learning at RMIT, and in this survey students were asked to rank various facets of the DSP unit, with the ranking being 1, 2, 3, 4 or 5. A ranking of 5 corresponds to a very positive ranking, while 1 corresponds to a very negative one. 70 students responded. For 4 of these 15 different facets, the modal (i.e. most common) ranking was 5. For 10 of the facets the modal ranking was 4. The only facet which scored a low ranking (of 2) was "adequate provision of facilities (i.e. rooms, equipment, labs, computers, etc)".

Additionally, the students were asked in the survey to provide their own additional comments on the subject. It was of interest to see how many of these comments related to the seven attributes targeted in Section 2.1. Six positive comments were recorded about the lecture notes – c.f. attribute (a) in Section 2.1. Seven positive comments were made about the lecturing being helpful to student understanding (c.f. attribute (b)). There were eight positive comments about the effective way that theory was related to practical applications (c.f. attribute (c)). There were no comments about the usefulness of the multi-media resources (c.f. attribute (d)). There were eleven positive comments about the lecturing staff being friendly, helpful or approachable (c.f. attribute (e)). There were sixteen appreciative comments about the humour of the lecturer (c.f. attribute (f)). There were 3 favourable comments on the organisation of the course unit (c.f. attribute (g)).

There were also several negative comments made, which will provide some motivation for future improvement. Many of these negative comments related either to the fact that too much work was covered (9 comments) or to problems with room facilities (9 comments). While there was little comment in the survey on the availabil-ity of the multi-media resources, Collaborator 1 received an email at QUT from an RMIT student stating that the flexible resources had been extremely helpful. Other students commented informally that having the flexible resources available on CDs would greatly increase their usage and effectiveness. This is planned for next year.

Benefits of the collaboration and conclusions

Theory indicates that collaborations benefit the participants through synergies. i.e. through the efficient groupings of ideas and resources [5]. This has occurred in the case study at hand. The collaboration has “fast tracked” the creation of extra resources, and conveniently, the cost for these resources has been shared across institutions. The fact that these resources have to be used in two different environments has also meant that they have been compiled in a comparatively “user friendly” format. The cross-fertilisation of ideas has been effective as well. Collaborator 2 employed independent survey mechanisms for the first time, and cross university surveys are being organised for next year. Encouraged by the extraordinary student response about humour in lectures, Collaborator 1 is also aiming to introduce more humour into his teaching.

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Sustaining Excellence by Eliminating Plagiarism

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Abstract: *plagiarism, particularly in university software subjects, has the potential to dramatically reduce the competence of a significant part of each class. If left unchecked this reduction in competence could cause employers and the community to question the credibility and relevance of a given university, and universities in general.*

An anti-plagiarism activity that focuses on a quick fix with anti-plagiarism tools will probably fail because the prevention of plagiarism is a complex cultural and systems issue not a mechanical process of using tools to catch the perpetrators. This paper argues that a better path is to analyze the big picture using a quality assurance method called How-How diagrams, work through a system design process, make adjustments to the curricula and work processes, and finally select and use anti-plagiarism tools.

Keywords: *plagiarism, quality assurance, How-How diagrams.*

Introduction

The introduction of fees has started a subtle opening up process of the tertiary education market. Students and employers are evaluating the costs and benefits of awards and providers in a way we have not seen before. This author has been bluntly told by an employer that if a potential employee had passed a CISCO and Microsoft accreditation course they are more useful than a university graduate.

Universities need to respond to this competition by communicating to employers, students, and the community at large, the advantages of a university education over other forms of education. The university system may also need to adapt in the face of competition and justify their costs.

> *Test*: do full fee paying graduates at your university say "I only paid X thousand dollars for my course and that was good value!". If they don't then competitors will be eyeing your market share.

In order to deliver on these big picture goals all Universities must be able to warrant that their product (a university education) is of good quality. A major blot on this warranty is the reality or belief of wide spread copying (plagiarism) that dilutes the quality of the product and the public's belief in it's value.

Newspaper articles and TV reports have been quite damaging and have negatively effected public opinion. Consider the articles in the Melbourne Age by Milavanovic (2003) titled "RMIT student gets bond for cheating charge" and by Szego (2003) "Shock finding on uni cheating". The university's reportedly weak response to cheating has not helped the public image.

In the current environment plagiarism elimination is not simply some academic chase for purity or a quest for the "good old days when things were better" but a business imperative for any university that takes a long term view and values its reputation.

This paper does not attempt to solve the big picture problems rather one important issue that is more under the control of academics - the elimination of plagiarism. It reports on the response to the plagiarism problem by RMIT University's School of Electrical and Computer Engineering (ECE).

Not So Simple

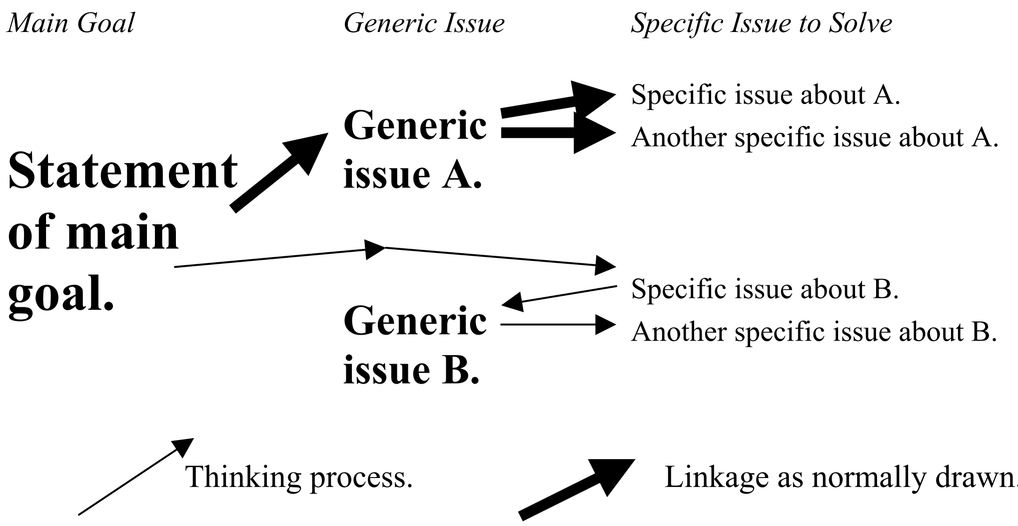
At first glance the plagiarism problem appeared to have a simple solution: the use of plagiarism detection tools should stop plagiarism because the risk of detection would deter students from cheating. Discussion and focus groups with staff and students in ECE quickly showed that plagiarism is a complex issue and that the thoughtless application of tools would not solve the problem and would most likely waste money, time and effort. Perhaps even worse a policing approach based on tools may develop undesirable attitudes and culture in the student body.

The complexity of the plagiarism issue soon became too great for convenient representation in simple text and there was a concern that important issues may have been overlooked. We turned to How-How diagrams as a method to solve both these problems. First the general use of How-How diagrams will be explained and then they will be used to list the plagiarism issues we identified. These issues will then be discussed in detail.

How-How Diagrams

How-How diagrams are used extensively in Quality Assurance as a way to stimulate ideas, to foster group discussion, and as a way to organise and document ideas (Juran 1988). They also aid the problem solving process.

One particular feature of How-How diagrams is that they help identify both general issues and specific issues to be solved that may otherwise be missed. Consider the How-How diagram below. Given a problem statement the human mind will often leap to a specific solution (from "Statement of main goal" to "Specific issue about B"). The How-How diagram method simply requires us to look for a more generic statement of the specific issue (from "Specific issue about B" to "Generic issue B"). Armed with this new generic issue it may be possible to discover more specific issues to solve (see "Another specific issue about B").



The process of using How-How diagrams, either as an individual or a group, thus becomes-

- Agree on a main goal.
- Attempt to identify generic issues and specific issues.
- Group specific issues under generic issues; if there is no suitable generic issue create a new generic issue.
- Examine each generic issue to try and derive more specific issues.

How-How diagrams have many variants. They are commonly used to detail the issues related to a goal (as above), or to develop details how a goal can be achieved.

Plagiarism How-How

The plagiarism problem analysis in ECE use the following statement as a main goal-
"How to design a workable plagiarism elimination program".
The emphasis was on a system that works in practice and avoids the many pitfalls including political, organizational, practical, and technical issues. The diagram that follows shows the issues identified so far, though not the iterative development process as described above.

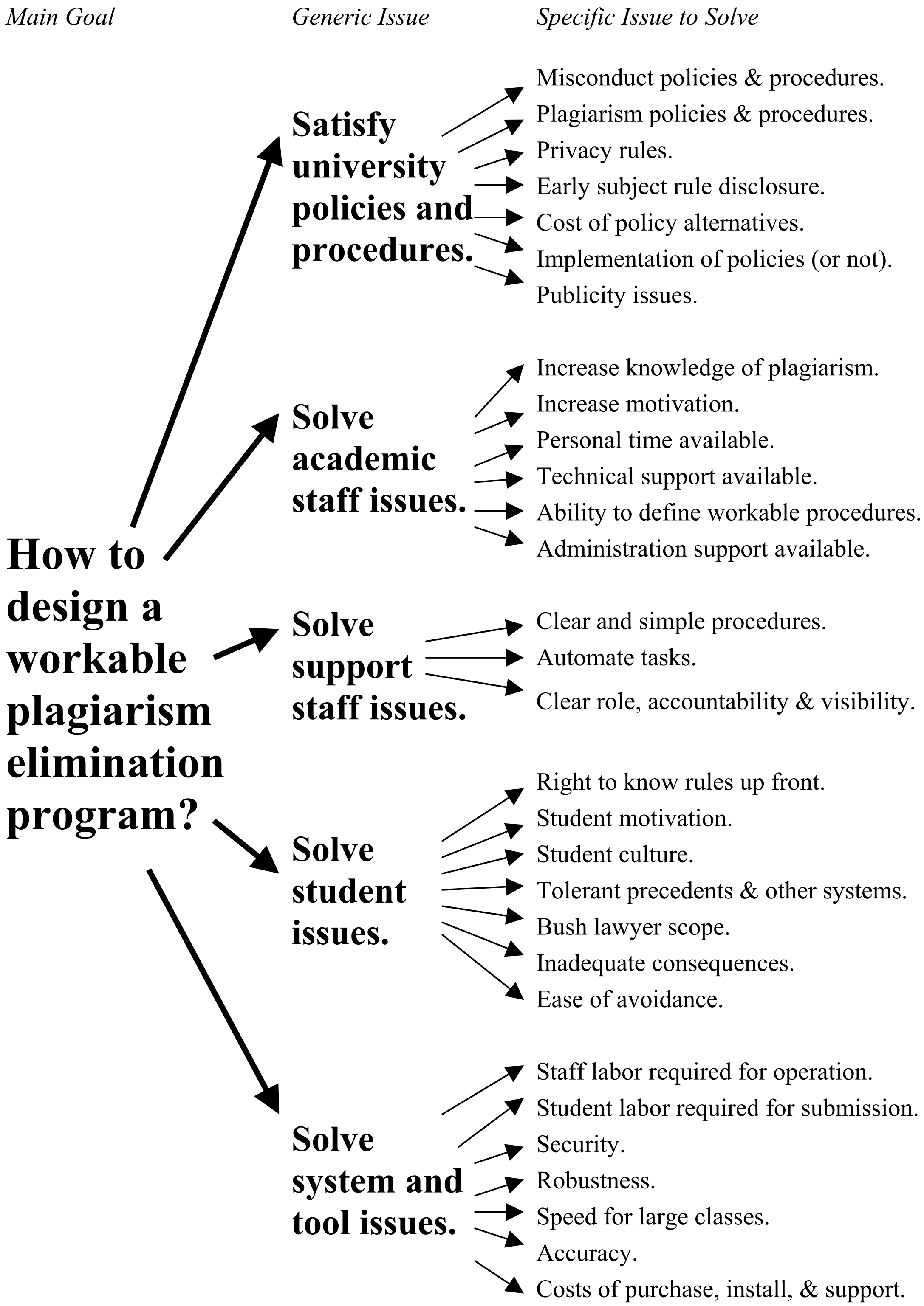


Figure 1 : Issues to resolve before tools are decided.

The following sections discuss key issues identified on this diagram, and possible solutions.

University Policy and Procedure Issues

A key activity for an anti-plagiarism activity is to discover relevant policies from all sources and how they might affect an anti-plagiarism program.

The university has an important role in defining enterprise wide standards. All decisions by departments and schools must fit within these guidelines and any activity that violates these guidelines will eventually be called to account and ruled invalid. Most universities place their rules on the web. Local policies at the faculty, department or school level are often a problem as such policies are seldom visible on the web and may not even be written down. Local policies tend to be more volatile and change more quickly with time. There is certainly legal opinion that if policies are not written down and available to everyone then they do not have any weight.

In general the execution of policies at the university level is a time consuming, drawn out affair that may become political. Quite often any deviation from official procedures by the university results in all charges or penalties being dropped on any appeal by the student. Such deviations are quite common, particularly with local undocumented processes. This can be incredibly frustrating and demotivating for staff and engenders disrespect from the student body toward the university.

In order to avoid the waste of time and frustration it is best to devise a system where penalties are immediate, local, and difficult to reverse so that University processes need not be brought into play. The system must fall within policy guidelines or it will be easily challenged and beaten.

Academic Staff Issues

It is difficult to ask staff to do more in a general atmosphere of funding cuts, higher workloads, and in some cases a depressing work environment. An anti-plagiarism program will fail unless staff feel motivated to make it work. Motivation must be nurtured starting with education about the degree of plagiarism, the consequences for a department's and individual's reputation, and the nature of anti-plagiarism tools. Many other factors come into play -

- Active management support.
- Availability of tools and resources.
- Lack of bureaucracy in the response to plagiarism. Excessive process can soak up inordinate amounts of staff time and given current staff workloads this is untenable.
- A local champion can help overcome teething problems and show how a simple yet effective system can be implemented.

Support Staff Issues

Many anti-plagiarism programs will require some use of support staff ranging from office staff who accept project work to technical staff who maintain the network. These people cannot be expected to be enthusiastic about the program and so what they need to do must be well defined with clear written requirements and procedures, and ample warning of what is needed from them by what time.

Student Issues

Students expound many good reasons why universities should be tolerant of plagiarism and unless academics specifically address these issues then student culture will remain unchanged, and will remain tolerant, even supportive, of plagiarism. In some cases the student's arguments are quite valid and academics need consider driving changes both at the work process level and the curricula level. In other cases the student's perception or attitude is causing a negative learning outcome and the academic needs to take a leadership role in engaging the student body and adjusting the student culture.

This author has run several small focus groups of third and fourth year students in the ECE course at RMIT and has interviewed many students who have been caught plagiarizing. The results are similar to those reported by other academics (e.g. Ryan, 1988). The most common pro-plagiarism arguments, stated from the student perspective, include-

- "I think this subject is poorly thought out and far too much work. Group work (plagiarism) is the only viable solution."
- "I want to specialize so I will pair up with someone who loves another subject and we will swap work."
- "I need to work to pay HECS fees or other reasons, copying is the only way I can survive."
- "I am forced to do subjects I hate that are totally irrelevant to my career."
- "I can't cope because of poor teaching in previous years, lack of tutorials, and poor resources."
- "In industry you copy everything you can so why do it differently here?"
- "It happens everywhere so why target me?"
- "This is the only subject I have trouble with."

The Quality Assurance guru Edward Demings made a very pertinent comment on worker performance (Juran, 1988)-

> "To call the attention of a worker to a careless act, in a climate of general carelessness, is a waste of time and will only generate hard feelings, because the condition of carelessness belongs to everybody and is the fault of management, not of any one worker, nor of all workers."

In short, it is the responsibility of academics to engage the student body and foster a positive change in the student culture.

There are a whole range of things that can be said that will change student culture (AUTC, 2003). These are best explained in the first lecture of a subject-

- Admit the relativity of marking "In reality there is always an element of relative marking, if you do well and others do badly then that will help your mark".
- Remind students of the collegiate value of a degree, "The reputation of your degree depends largely on the quality of other graduates. Do not endanger that reputation by helping people to graduate with inferior skills."
- Give students a clear definition of plagiarism and how to avoid it (Carroll, 2000)
- Explain how giving answers is not helping the recipient, "By giving solutions you discourage people from improving their skills. In later years they will most likely be caught out, so don't give solutions and so help people get better.".
- Acknowledge and perhaps accept the industry approach of copying everything, "The only time it is wrong to copy in industry is when you get sued. Re-inventing the

wheel is a waste of time and money. In this university we must measure your skills as an individual, so copy all you like but you must acknowledge the source of everything you copy."
- Remind students the main goal is to become skilled, "your main goal is to improve your skills and get that first job, employers are harder to fool than academics."
- Publicize anti-copying strategies and tools.
- Clearly articulate university policy.
- Draw attention to detection methods and punishments.

The design of assessment items and student work processes can also minimize plagiarism (AUTC, 2003). Examples include-
- Give students randomized problems, for example different cutoff frequencies in an electronic filter design.
- Use of innovative marking schemes that discourage copying. For example tell students "You will be rewarded for innovation and novelty so keep your good ideas secret."
- Change assignments, labs, and projects from year to year to stop plagiarism between years.
- Place minimal marks on assignments but then base a significant part of the exam on the assignment.
- Develop a level of competition by having a variety of small prizes for the major project in the subject.
- Develop marking guidelines that encourage competition, such as class list marking or the military standard bell shaped distribution for class results. These approaches violate the policies of some universities.
- Require weekly submission of code into CVS repositories and check the weekly differences between versions. This would detect major, sudden, last minute developments which are characteristic of plagiarism.

System & Tool Issues

Anti-plagiarism systems are indeed systems and must be analyzed and designed from a systems perspective. Mistakes at the detail level can result in an unworkable system that frustrates everyone and will delay by years the introduction of a working system. Typical system design tasks include-
- Proposing a complete workflow process, probably using block diagrams or Data Flow Diagrams.
- Estimate the labor time for staff and students for each process.
- Carefully examine the effect of class size on labor time.
- Look at ways in which labor can be minimized.
  Identify opportunities for automation, especially if tools may already exist.
- Consider the skills of staff and students to use any automated systems.
- Identify scope for abuse and fooling of the system.
- Run a pilot program to prove the system before general use is encouraged.

Labor costs can rise dramatically with class sizes. Consider a simple task such as taking floppy disks from an assignment pigeon hole, and sorting them into a box for each subject. Realistically this may take 30 seconds a disk and with a class of 240 students this represents two hours labor just for one subject. Administrative staff may simply not have that time free.

Consider the labor of using a program that compares two documents and gives a single figure of merit for document similarity. The number of comparisons that must be made for a class of size n is ${}^{n}C_2$ or n(n-1)/2, approximately $n^2/2$. In a class of 10 this comes to 45 comparisons, given a class of 240 this comes to 28,680 comparisons and if each comparison took only ten seconds the total comparison time would be about 80 hours not including ranking or follow up.

Students can be mischievous and any system weakness will be punished. Some students will make claims that the system is faulty to hide their own shortcomings. The system design must identify possible abuse scenarios and develop mechanisms to avoid abuse. There is often a tradeoff between system robustness, usability and cost.

- Student claim "I am absolutely certain I handed it in, you have lost it!"

  Solution 1: in a web based submission system give the student a receipt number that encodes the student number and date. It is the student's responsibility to record this number. If the student does not have a valid receipt number then their claim is not accepted.

  Solution 2: in a paper based submission system the student gets a signed or stamped receipt from office staff. No receipt means the claim is not accepted. Bar code based systems can help reduce staff labor and track assignments through the system.

- Systems can be stressed for example by submitting huge files that clog the file system.

- Systems that lack password protection can be spoofed easily. Students can put in bogus submissions for other students and the whole system descends into chaos.

- Web based systems can have HTML or PHP commands placed in data entry fields that then damage or discredit the system. Some knowledge of network security and abuse methods can save severe embarrassment later.
  (In one of our early web prototypes anonymous students posted comments that included .gif files of staff member faces atop other bodies...)

- Assignment return systems can also be abused. Unsecured returns are pilfered by lower year students who will copy the solutions next year.
  (This author has heard students comment they must have got a good mark because their assignment was taken by someone else.)

Current Status

The author's main application is with software assignments in the School of Electrical and Computer Engineering at RMIT. The How-How approach has helped to avoid a variety of problems and has certainly saved time, effort, and possibly embarrassment.

The issue of university policies is crucial and must be given early attention. If the policy issues are not resolvable then it is not worth the effort of running an anti-plagiarism program as the risk of university rejection of the scheme is too high.

From our experience the issue of student motivation is probably the biggest single issue. This places a responsibility on the academics to clearly communicate the issues and change student culture.

The current status in the School of Electrical and Computer Engineering is-

- RMIT policies support anti-plagiarism activities. Student rights are extensive and must be respected.
- Staff are worried by plagiarism and there is a will to eliminate it. Many subjects use organizational and motivational innovations to limit plagiarism.
- A number of staff clearly expound the anti-plagiarism message but this could be more wide spread.
- Penalties for plagiarism are spelt out in many subject guides so staff have a "legal" basis for enforcing penalties. These penalties are local and immediate.
- No tools currently exist that cope well with our large class sizes and project types (classes in excess of 300 students and multi-file projects).
- No funds are available for tools or labor thus we are limited to GPL tools and what we develop ourselves or with projects from our better students.
- Academic staff time is at a premium thus the system must be as fully automated as possible.
- This paper deliberately did not dwell on the technology of plagiarism detection but after searching the literature and small scale trials we have decided on a detection algorithm and system design. We hope to have anti-plagiarism tools completed for use in late 2003 or early 2004.

Conclusion

Plagiarism is indeed a complex issue with significant cultural and systems issues. Any attempt to use anti-plagiarism tools without considering these issues is probably doomed to failure. This paper has identified many issues and all appear soluble though this may be difficult given an environment of tight staff and monetary restraints.

University policies and procedures must be an early consideration as these are usually immutable and can effect the viability of proposed solutions. Academics have many responsibilities and tasks including student consultation, proper curriculum development and leadership in the area of work place culture. Support staff issues are a major consideration in a climate of restraint and the need for such staff must be minimized.

The student body and individual students should be seen as the major beneficiaries of an anti-plagiarism program. The benefits may include a better and modified curriculum structure, a better work culture, a better learning outcome, and a better respect for the degree title.

At RMIT School of Electrical and Computer Engineering we have done the initial planning of an anti-plagiarism program and hope to introduce it in the near future.

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Acknowledgements

To most students who work hard, don't copy, and so graduate with skills and knowledge of which they can be proud.

Combating student cheating in Academia

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***Abstract**: World wide, the stakes in education are higher than ever. An academic qualification can be a ticket to a better world and even to a better country. Frequently, university fees of around $20,000 or more a year are incurred in studying for a degree. Entrance into a desirable educational institute depends on good grades. The pressure to cheat, and the opportunity to do so has expanded enormously. The Internet and explosion of information sources, together with high technology, make the methods of cheating much more diverse and effective. Apart from age-old cheating in examinations, tests and assignments, cheating by having a substitute sit the examination is also becoming common. With the large growth in numbers of students attending many academic institutions, staff frequently does not personally know the students and thus cannot easily detect substitute candidates. Distance learning, where the academic may not meet the students at any stage, gives rise to easy opportunities for substitution. Student ID cards are not difficult to forge with readily available technology. Such is the state, that the reputations of academic institutions is at risk and it is well to be aware and to combat cheating of many and varied types. In this paper, some of the typical manifestations of cheating are described together with some traditional and some recently developed automated remedies.*

***Keywords**: cheating, academia, remedies.*

Introduction

Many idealistic academics don't want to believe such practices are occurring and literally don't want to hear about it. The institutions often react weakly to detections of cheating. Fear of bad publicity, desire to avoid hostile legal action and the expediency of sweeping the matter under the carpet, often result in little or no penalty for those caught behaving dishonestly.

Ultimately, the reputation of the universities and the trust of employers and society in academic qualifications stand to be seriously eroded, with consequent unfair damage to honest and honorable students.

Academics and their universities first face the problem of cheating when selecting new students, particularly offshore students as the university has little ability and resources to check claims or documents. In a report in The Age, (14 May 2001, p. 8) Bangladeshi college students went on a rampage because their attempts to cheat in an English examination were foiled by police. *"The students became violent when they failed to get prepared answers for the English question paper, one police officer said."*

At RMIT as reported by Hunt (2003), a computer science student paid his tutor $800 to sit his examination. The tutor was not charged and the student was later allowed to re-sit the examination. The newspaper article claimed “a survey revealed cheating was rife in Victorian universities. Almost 8 per cent of students surveyed confessed to some form of dishonesty.” In the same article, a survey conducted by the info-tech faculty at Monash University, of 700 undergraduate students at Monash and Swinburne universities, reported that 3% of students in info-tech admitted hiring someone to sit examinations for them.

Professor Allan Patience professor of political science at Victoria University expressed the following fear: “We are in very serious danger of making degrees totally meaningless and unleashing unqualified graduates into the community.”

But the problem is not specific to any one country. As reported by Kelly (2000), Professor David Presti of the University of California, suspected that some cheating was occurring in his advanced-level neurobiology classes. He used an online service providing checks for plagiarism and found that 45 of the 300 papers submitted to him had significant plagiarized content, despite the students being warned beforehand that plagiarism checks would be conducted. This number exceeded the total of all other cases of plagiarism detected by other methods that year in the whole university.

The problem extends beyond what might be called one-way plagiarism. Web sites are now online that offer a range of services for cheating, extending from a catalog of standard project reports that are not original, to new original reports written to specification for the customer. Such reports, being quasi-original, are very difficult to detect as being not the work of the student. However, even such “original” reports, if written for a number of customers on the same topic by the same author, will contain surprising commonality that is readily detected by plagiarism detecting software.

Two typical sites supplying written essays are www.cheathouse.com and www.cheater.com. One comment recorded in the first site is (sic): “College Application Essay for Computer Science Major. I wrote it and used it, got accepted to the 3 schools I sent it too, now someone else can use it too!”

This site claims to have 15,000 essays online on a range of topics. Cost is around $9.95 per month and this allows unlimited access. Custom written essays typically cost $20 to $30 per page and can be supplied in as little as five days. A representative web page of schoolsux.com is shown in Figure 1

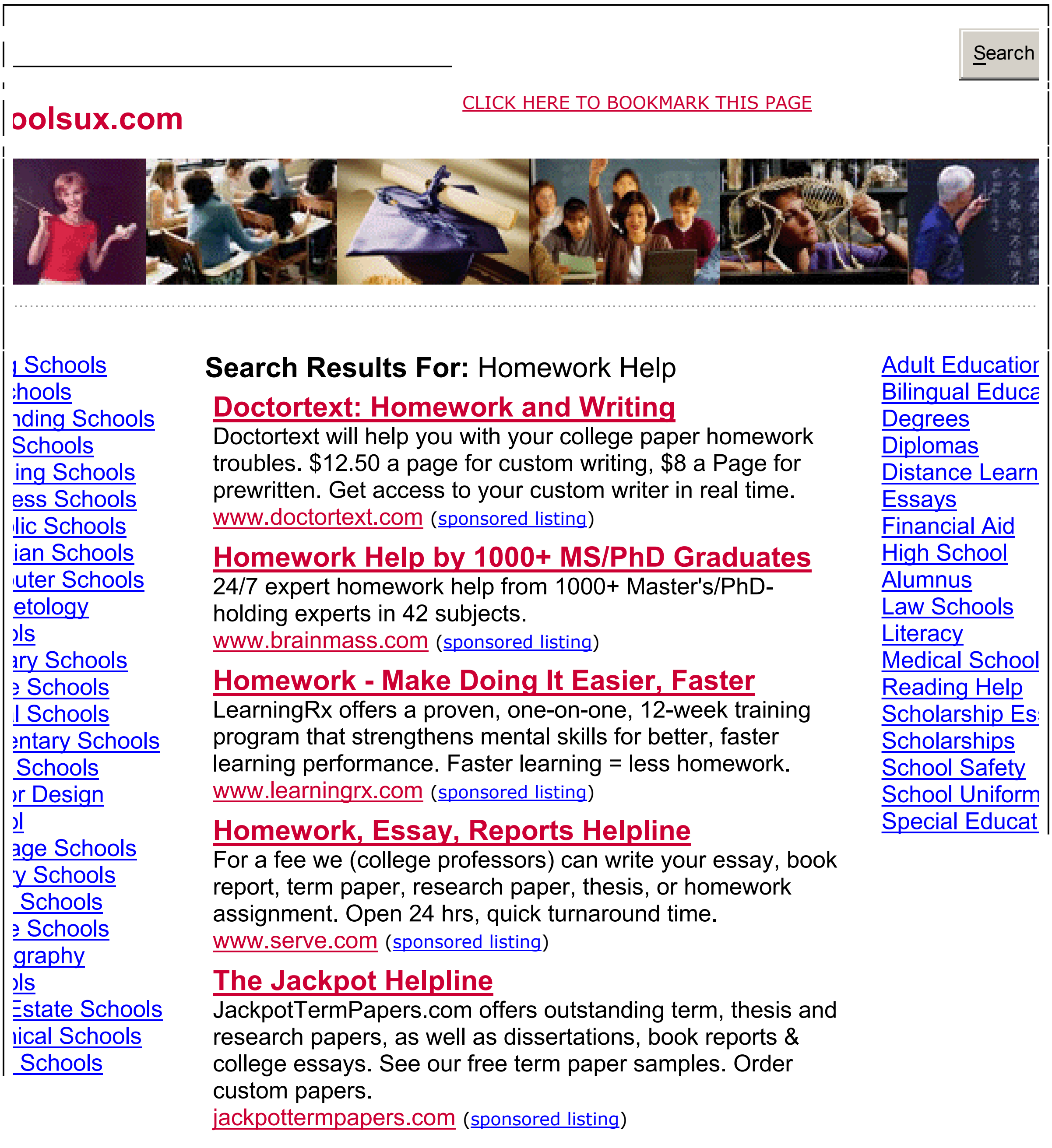

Figure 1: Schoolsux web page.

A different type of cheating is direct purchase of fake qualifications, usually to obtain a job but often to gain admission to a university or college. In the Singapore newspaper, the Straits Times, Kin (2002) reported on a “Buy a Degree” website operation. One cheat who was caught, had procured a forged university law degree purportedly from the University of London. He received a fine of $S10,000. As a test, Kin bought a Cisco Systems-certified database administrator qualification for $S4000 and subsequently verified that, as promised, his name was listed on the Cisco Systems website as having passed the necessary examinations. He also bought a fake degree for $S6000 and had his name registered at the Lancaster University as having attended and passed the course.

A less complex method of fabrication of qualifications, is to have the certificate or degree forged. A Melbourne woman employed a calligrapher to provide her with a fake university law degree certificate. The fake qualification was only exposed when she appeared before the courts on charges of defrauding her own family of a large sum of money whilst practicing as a lawyer.

Universities have little control over forgery of various qualifications and academic record. Such cheating is a major problem for academic institutions when the fake records and qualifications are used to gain admission to degree programs. Since admissions officers have little other information to go on in accepting and enrolling students, particularly for overseas students, this is a grave problem.

Cheating in Examinations

Many ingenious methods have been detected, ranging from substitute students to use of text-based messages (SMS) on high tech cell-phones that appear to be calculators. Calculators have also been used to carry large amounts of textual information into examinations.

In another case, a student managed to obtain a copy of the script paper before the examination and filled it with notes. He then left it in plain view on the desktop, knowing it would be mistaken for one of the script books handed out for recording the examination. The ruse was only detected because another student brought the deception to the attention of the supervisor. Leaving material hidden in lavatories and elsewhere is also common according to veteran supervisors. In a recent case of a more ingenious method of obtaining notes in examinations, a student having an examination in a “clash” room, bluetacked a sheaf of notes under the desk in which he was to sit some hours later. Unfortunately, the seating order was scrambled under a new policy to prevent pre-arranged copying between adjacent students. This particular student upon discovering this change to his careful plan, modified the seating list that was outside the room by “whiting out” the name of the student in “his” seat and swapped it to the seat he had been given. He cheating was later detected in the examination only because the Bluetack gave way and all his notes fell on the floor.

With large numbers of students and multi-choice questions, it is relatively simple to copy the adjacent student’s numerical selections, as the seats are often only a few tens of centimeters apart. Multi-choice questions are becoming the questions of choice for many examinations as they can be automatically graded, a critical cost saving with large cohorts of students. Thus such cheating of this type is a considerable problem.

Assignments, projects and laboratories written outside the supervision of the university, are wide open to copying of data and other forms of cheating. Candid admissions by past students to having “workshopped” the laboratory report or assignment, with a circle of fellow students, is common. This being so, such assignments and reports are virtually useless for assessment purposes.

Remedies

In the case of multi-choice question examinations with large numbers of student, a simple remedy to copying from nearby students, is to run two examination papers, each down alternate rows. The examination papers contain the same questions, but in different order. This is most effective in confusing the issue for would-be-copiers and is simple to effect. The author has caught a few students "doing the other paper" but knowledge of two versions of unknown variation is usually enough to inhibit copying. In any case, cross copying between scrambled-order papers is automatically punitive with grade results reverting to those for random choice of answers.

Laboratory exercises should be written up and submitted before leaving the laboratory. Students hate this, as extensive preparation must be done in order to have any chance of completing the experiment on site. However, the beneficial affect of such preparation on learning is, in the author's experience, profound. The other objection to the practice of immediate write-up and submission is that the students need time to think about the results and to process them. This may be so, but with rampant copying, the gains are arguable. The benefit in comprehension and learning, of intensive preparation required for on-site completion of the laboratory, is of major benefit. In any case, the integrity of later write-up and project execution can only be made verified by supplementary supervised testing on the produced material. Without this the operation is often a charade.

Excessive trips to the lavatory or bathroom during examinations need to be carefully controlled to prevent rendezvous and sharing of information between students. Pre-clearing of any information in the toilets can also be effected.

Substitutes are more difficult to detect. Distance learning courses where the material is delivered remotely, using online facilities or mail, are particularly prone to substitution cheating. It is essential that clear photographs of the candidate be obtained early in the course to preclude later opportunistic substitution. In one instance, the author was startled by the unsolicited statement in a social context by two young students from another university, that paid substitutions between students at different universities located nearby, are not uncommon, with the example given in this case in an accounting course.

The only remedy appears to be vigilance and use of smart cards or at least photo-ID, although even photo-ID can be readily forged.

Fake entry qualifications and academic records are an ongoing and vexing problem. Their considerable use is suspected in postgraduate programs offered to overseas students. The payoff for the successful offender can be high as such programs, in effect, are also commonly defacto immigration schemes in Australia. Once the degree is obtained, the recipient can apply for permanent residency. Enrolment officers frequently cannot employ independent tests, verbal or otherwise, to quickly expose such fraud. It has been the practice of the author to fire simple questions at students asking for course exemptions because of other equivalent experience. In one memorable case, the student was not able to answer any one of thirty very basic questions. He clearly knew nothing about the topics, despite having paper qualifications that indicated that he knew the subject well. However, such verbal checking is resource-intensive and thus has very limited application.

One of the factors in the increase in cheating, the web, can also be also used to combat cheating. Online services, such as http://www.turnitin.com can be used to check for plagiarism. This facility, available to individuals or institutions at commercial rates, will accept electronic versions of essays for example, and do a web search to check for plagiarism from web sites. An example of a report from this facility is given in Figure 2

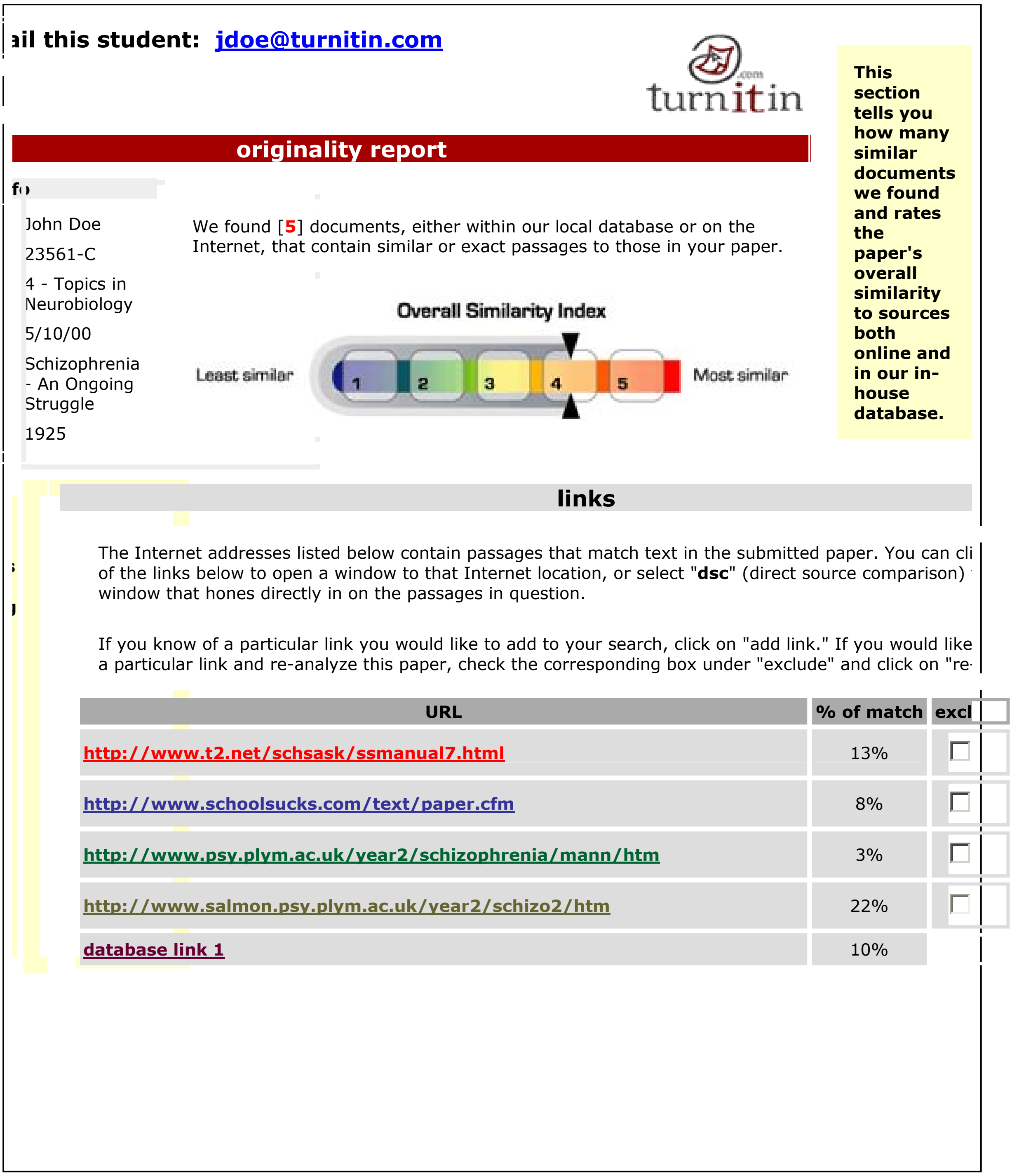

Figure 2: Example of an online plagiarism report.

Another electronic defence is in the form of plagiarism-checking software, that checks for copying within groups. In one recent incident, 20% of submissions were found to have large areas of commonality. It was found that a tutor was writing essays for his students for $300 per essay. Although “original”, the essays had large commonality as they were produced from the same mind and on the same topic.

Conclusion

Cheating by students is rising and becoming a serious problem for academic institutions and employers in particular. The main forces driving the rampant increase are high financial and personal stakes for students, the ready availability of resources for cheating - both online and amongst peers, the change in culture that regards cheating as quasi-legitimate, and the high probability of the fraud not being detected or seriously punished.

The tendency of authorities to cover up or ignore instances of cheating also has contributed to the growth in cheating. The naiveté of some academic staff who often accept on face value, scraps of official-looking paper as a true academic record of the student presenting it, is also sometimes startling. Others "want to focus on the happy bits" and thus ignore if possible, the unpleasant need to deal with cheating. Both mindsets promote abuse and degrade the academic processes.

The willful disregard, by developers of online remote assessment, for the problem of ensuring integrity makes their efforts futile in the long term. Nevertheless, universities are generally proceeding down this path, with the promise ultimately of further destruction of university and graduate reputation and despair of employers.

Simple remedies combined with sophisticated techniques such as plagiarism checking software, can be very effective in a range of situations but solutions to false academic records is difficult to counter economically.

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Engineering Education: Sustainability in the 'Knowledge' Economy

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Abstract: *Significant reforms have occurred across the tertiary education sector aimed at building a tertiary sector to support of the development of a knowledge economy and society. In this discourse, sustainability has, to a large extent, been absorbed by the imperatives of production – and yet not completely as seen in the 'battle fields' described by institutional power, pedagogy and philosophical traditions within engineering education. Given the problematic nature of the ongoing work to integrate sustainability across the disciplines of engineering education, the paper proposes an approach to understanding engineering education, and potentially, the mechanisms through which significant pedagogical change can occur. Engineering education is viewed from the perspective of a 'community of practice' which reflects the core fundamentals of sustainability: community and interconnectedness.*

Keywords: *community of practice, knowledge, transformative, sustainability*

Introduction

Social commentators argue the penetration of scientific knowledge into not only production, but most spheres of social and cultural life – the process of 'scientisation' – has essentially transformed the productive basis of society (Guile, 2001). Knowledge has superseded traditional factors of production, such as land, labour and capital. The resulting 'knowledge' societies are characterised by a growth in spheres of work beyond direct, material production. While there is debate [1] over precisely which type of knowledge is most important in economic development, there is growing recognition that the 'enhancement of New Zealand's future quality of life will be increasingly reliant on scientific knowledge and technological know-how' (Upton, 1996).

Universities have an increasingly defined and critical role in developing a workforce capable of meeting the demands of the knowledge economy and society (NYAS, 1996, TEAC, 2001b). This role is 'not just in terms of volume but also matching supply with demand for a skilled workforce of scientists, technologists, technicians and support staff to enhance the competitiveness of *existing* industries, as well as developing *new, innovative* areas of science and technology' (RSNZ, 2000).

Significant reforms (since 1985) across higher education have been undertaken throughout the OECD aimed at building tertiary education systems capable of supporting the development of a knowledge economies and societies (Stonyer & Marshall, 2002). In NZ, the

Tertiary Education Advisory Commission (TEAC, 2000) reiterated the need for intentional or proactive steering of the tertiary system to achieve these aims. TEAC identified five national strategic goals to guide the tertiary system: innovation, economic development, social development, environmental sustainability and the Treaty of Waitangi.

In spite of the inclusion of the concept of sustainability by TEAC (in this instance) in the political rhetoric, contemporary economic growth rhetoric subordinates sustainability to the imperatives of production (Davison, 2001). Davison goes on to argue that 'theoretical and technical knowledges are of course necessary for the flourishing of human life, but they are not sufficient for it. They lack the capacity to produce wise action' (p162). Here, 'wise action' has the inference of including but not limited to: cultural, moral, ethical, aesthetic, value judgements. The modern approach to engineering and science has been to deal with contextual complexities by avoiding or modelling them away; therefore to realise 'wise action', engineering and science for sustainability must become more embedded in social systems (Berke, 2000).

Challenge and change in engineering education

Clearly, the context in which tertiary engineering education (both locally and internationally), exist is a contested terrain defined by three planes (xyz). On one plane we are charged with the task of developing 'new knowledge' which delivers to strategic national goals in social and economic (and to a lesser extent, sustainability) spheres. On the other plane, our resource and activity base in tertiary education remains committed to traditional models of knowledge production and practice rendered compliant in the main to economically determined interests [Goldman, 1991]. And, on a third plane, we must realise sustainability. I illustrate the effect of these tensions from three spheres formed as the planes intersect, which I have named: power, pedagogy and philosophical traditions.

Power

Conceição and Heitor (1999, p1) discuss the contemporary role of the University, 'based on recent conceptual approaches to economic growth namely, in terms of the accumulation of knowledge, as being the fundamental driving force behind growth'. They argue that 'the University must respond to changes in the world that challenge its well-established pedagogical and epistemological traditions or face loss of institutional respect and power' (ibid). To illustrate: one feature of the TEAC recommendations is the joining of economic and social aims of learning in the concept of 'life long learning' (Mehaut, 1999, Forrester et al 1995) where learning is placed at the heart of economic development. This concept has informed efforts to adapt, modify and extend traditional models of professional science and technology education to ensure graduates can maintain and develop their vocational practice throughout their working life (Candy et al 1994). In the main, however, the ideas of 'lifelong learning' are based on narrow ideas of 'learning' – that learning is the acquisition of pre-existing knowledge and skill (Guile, 2001). Jim Watson (2001), founder and chief executive of the successful New Zealand biotechnology company Genesis Research and Development, states that 'the 'young' are the standard-bearers of our scientific revolution…. they must be encouraged to discover the paths of the future, not trained in the ways of the past'. A challenge indeed, if the figures quoted by Orr (1998) in discussing an annual survey of first year students which indicates that nearly 75% of incoming students prefer to being ''well-off' to developing a philosophy of life or improving their minds', are equally applicable to our student cohorts!

Pedagogy

As engineering educators we have begun to address the inherent tensions between the *existing* and *new* in our pedagogy within this contested space, adapting and modifying curricula in response to the reshaping of the social and economic spheres. The challenge:

- that we had grown too far from industrial practice has seen our response towards industry/university collaborative workplace learning projects and embracing capability development;
- to redesign curricula to reflect development of new techniques in our practice has seen the emergence of trans/interdisciplinary knowledge from blending engineering with and other disciplinary thinking ie biotech, risk assessment;
- to take responsibility for the initial formation of professional competencies underpinning effective practice has been realised by embedding relevant learning experiences within curricula.
- to connect engineering to the needs and issues of the wider community is being addressed through equity, society and engineering, history and philosophy of engineering approaches.
- of sustainable engineering means embracing ambiguity in dealing with a diverse array of hitherto unrecognised elements framing engineering problems and is challenging us to find new/other problem solving approaches. (Note the reduction of sustainable engineering to 'another' voice among many.)

As a result, each educational programme has a unique footprint depending on the particular pedagogical mix that reflects how the programme adopted, refuted or acquiesced to contemporary pressures to change. However, using such an eclectic approach to develop engineering curricula is not sufficient without being shaped and guided by an understanding of the way knowledge and competence are created, distributed and learned across the community of engineering. Such an approach can also limit the effectiveness of the transformation to engineering education because it fails to challenge the philosophical basis of engineering.

Tonso's (1998) work picks up on this theme. She describes the process of engineering education as 'not simply training in a prescribed set of appropriate, academic courses, but as enculturation into a well-established system of practices, meanings and beliefs' (ibid, p4). Her research documented cultural models of engineering (education and careers) systems. Cultural models are:

> 'taken-for-granted sets of ideas about how the world is supposed to work, are frames of reference that people use to make sense of, and debate, the meaning or interpretation of events … When a cultural model is invoked, it establishes one way of interpreting an event and in so doing it limits and simplifies the interpretations that people are likely to give to the event. (Eisenhart & Lawrence, 1994, p.98).

There are particular identities which are congruent with the frames of reference of a cultural model. Tonso's work documents how these identities are forged by students, give meaning to their actions and importantly, belonging and legitimacy as members of the engineering cultural community. Crofton and Mitchell (2000), for example, talk about the ways a student comes to 'know' sustainability as being 'not important' – through professors, the marginalisation of learning to 'outside' core curriculum elements, 'industry' viewpoints, rejection of things 'green' as being defined outside the 'true' engineering experience etc. Hence, students 'become' engineers who categorically state 'sustainable development has nothing to do with engineering' (apparently it's a policy issue) (ibid, p1).

Philosophical traditions

Davison (2001) writes 'modernist thinking asserts that the combination of ecological stability and techno-economic progress confers sustainability on human societies'. This is the thinking that states: 'we will find [scientific/engineering/technological] solutions for any problems in the future because we are the 'problem-solving' community'. It is the thinking that 'integrates all authentic opposition, absorbs all alternatives' (ibid). I have argued elsewhere that it is the scientific discourse of engineering, structured by the philosophical traditions of the Enlightenment traditions, works to define, limit and enforce the boundaries and conditions of engineering problems and their unique solutions(Stonyer, 2002b).

Unquestionably, it is important to maintain the distinctive features and characteristics of science and engineering education which have foreshadowed and enabled the very essence of the 'knowledge' based economy and society. But, as argued by Barke (2000):

> as long as the culture of engineering remains willfully separated from the social sciences and humanities, the uncomfortable questions raised by sustainability will continue to be viewed *as second class questions* (italics mine), unable to change the world. Incremental adjustments assume the ability of the environment to be patient.

He goes on later in his paper (quoting Thurston, 1999) – 'if engineering thinking dominates the relationship between sustainable technology and sustainable development, there will be disappointment in attempts to create a standard analytic structure that spans the complete domain'. I think we hear some of this 'confusion' in the wonderful retort quoted by Davison (2001, p42) … part of which is repeated here:

> … [Scotland] at least, according to the Approximately Environmentally Adjusted Net National Product method of measuring sustainability, they live sustainable lives. But hang on a minute. According to the Pearce-Atknison measure, Scotland was 'weakly unsustainable' between 1988 and 1992 … Ah, But relief is again at hand: Net Primary Production figures suggest that Scotland has a carrying capacity of ... more than 1990's estimated population. But oh dear, what's this? Ecological footprint and appropriate carrying capacity data reveal that ' in Scotland 20% more land is required than available …'

Where to?

Orr (1998) proposes that relative to the magnitude of the challenges ahead, this intervention within curriculum and operational directions of institutions which has been occurring for 20-25 years – has failed to 'dent' the problem. He argues the challenge of equipping students to participate in the building of a sustainable society remains the fundamental challenge to educational institutions at all levels. While not denying the excellent work, to date, achieved in integrating and developing sustainability curricula, for many engineering education institutions the climate of general lethargy and complacency towards sustainability means that all students learn about sustainability is that, it is, not very important (Crofton & Mitchell, 2000).

As educators there are major gaps in our knowledge and, indeed, our abilities to enact change regarding how engineering courses might best address the current and future needs of graduates. There are unanswered questions relating to what their future needs really are if engineers are to develop the 'pathbreaking' technologies required to meet *factor 50*. We have begun; shifting engineering education away from the traditional and fundamental allegiance to instrumental problem solving within a scientific worldview (Goldman, 1991; Holt, 2000) through responding to the social construction of technological action, problem based learning, systems approaches and the need for reflexivity as a graduate attribute. Personally, I remain unconvinced that the shift to the 'reflective practitioner' model of learning which is emerging – based as it is on an Enlightenment understanding of the individual, will prove to be sufficient.

In my view the metaphor of 'community of practice' provides a different, useful and, yet, familiar starting point. As engineers we identify with the notion of a community which maintains a continuity of purpose, but one which does change even if the change/transformation dynamics are not clearly understood, and our initial experience of this community via traditional engineering education culture is distinctly 'non-communal' ie highly competitive and individualistic! (Cordes et al, 1999). This aside, community is fundamental to sustainability. 'Sustainability is about community and interconnectedness at the core' and the university itself should be creating a 'sustainable living/learning community' (Conceição, Ehrenfeld et al, 2000, p34). How then to begin to create a sustainable living/learning community in engineering? The following sections address the origins of a community of practice and two complementary and essential aspects of this community: reproductive and transformative. I suggest the latter is the least understood in relation to engineering.

Communities of Practice

The concept of engineering as a community of practice (CoP) is adapted from situated learning theory (Lave & Wenger, 1991). The term communities of practice originated in the idea that professional community acts as a 'living' curriculum for apprentices to that community (ibid,; Mavor & Trayner, 2001). A CoP is a system in which participants share understandings that give meaning to: what they are doing; who they are (ie their identity); the knowledge, tools, artefacts and structures of the community. Meaning (and hence practice), however, is not fixed but negotiated within the community recognising that it is embedded in a historical and social context including both the explicit and tacit (Wenger, 1998, p47) knowledge(s). Later work by Johns (1997) links CoP to those of discourse communities who share practices and values that hold communities together (ie the 'culture' of a community'). This means we can consider the 'engineering culture', identified by Schien (1996), whose reference group is outside and across specific organisations/professional groups as being compatible with the concept of CoP. Communication links these ideas of community and culture together. Widdowson (1998, p5) states the seemingly commonsense:

> If individuals do not share a communal view, a common culture and the linguistic categorisation that which goes with it, then communication will prove difficult. … It is not simply a matter of knowing the semantic meanings of the words. For the words are schematically connected to form conceptualisations of reality which define the culture of a particular discourse community.

Reproducing Engineering Community

Therefore, a CoP is an intrinsic condition for the existence of knowledge because it provides the interpretive support necessary for making sense of these systems and how they have emerged (Lave & Wenger, 1991, p 98). In order to learn the nature and origin of this embedded knowledge, participation in the cultural practices of the community is essential. Learning involves the 'novice' sharing in the community knowledge - understandings, tools, artefacts and structures – in such a way that the novice is enabled not to talk about the knowledge of the community, but to talk from *within* the community as increasingly proficient practitioners of this knowledge. Talking/communication implies community and membership is mediated by the meaning of texts within the community that has implications for the role of language in learning to become a member of a community (Stonyer & Dodd, 2002).

Wenger (1998, p220) describes a learning community as a locus for creating, as well as acquiring, knowledge and involved in its own social reconfiguration through the learning of its members. The idea of that creation and acquisition of knowledge and meaning are embedded within a community enables us to join some of the disparate events in curricula. Emerging from the sociology of scientific knowledge are ways of categorising knowledge. Fleck's (cited in Johnston, 1998) proposed categories of knowledge, apart from 'formal knowledge', appear to be mainly 'learned' in 'experiential yet social' contexts of a 'learning' community. But, as Johnston (ibid) argues, an isolated piece of technological knowledge is useless (has no meaning or value) unless it is understood relative to the theoretical, evidential, application context in which it has emerged. Further,

> 'making use of any piece of knowledge requires a considerable investment in establishing the necessary interpretive context of theory, concepts, data and tacit experience. Further, it is only when the necessary 'complementary assets' of technological support systems, production capacities, and distribution networks are appropriately assembled that knowledge can be converted to a profitable use.' (Johnston, 1998, p5)

To illustrate this further, CoP provides a way of looking at how to develop pedagogy concerning occupational capability. In general, graduate attributes/capabilities have been defined externally to the profession – 'the political colonisation of the construction of competence' one commentator calls it - they have been contextualised according to the profession and/or occupation since they are not considered to be context free or completely transferable across different communities of practice. Defining capabilities in this reductionist approach can be problematic (Stonyer, 2002a). Capabilities thus defined can assume the 'status of reality' (Milton, 1999) – they are knowable, 'out there' ways of being a professional around which programme teams can develop and implement teaching and assessment practices to ensure students 'learn' these attributes. But these practices are often isolated from the 'experiential yet social' (Wenger, 1998) contexts of the CoP through which students can actually 'learn' those attitudes, values, practices which are important to the community (Stonyer & Dodd, 2002).

Critical for a community to reconfigure itself then is the reproduction of members who are capable and competent learners of all the forms of knowledge, ways of thinking and ways of practising their learning residing within the community. While professional cultures and communities are stable and resist 'deep redefinition' (Barke, 2000); they also change over time – change often being catalysed by new knowledge. In a situation where the 'formal' body of engineering knowledge has a 'half-life' of about five years and shrinking (Crofton, 2000, p399) then engineering community is faced with an ongoing need to redefine what is learned, when and for what ultimate end and therefore, what 'knowledge' will be the basis of community.

Transforming Community

One of the real challenges ahead for engineering education is to respond to Watson's (2001) call 'not to train in the ways of the past, but those of the future'. Watson in no way is diminishing the successful changes in curriculum to date, but points to a bigger task for engineering education – to begin to educate in such a way that communities can transform themselves. The question is how can we prepare learners for the unknown by means of the known? (Marton & Trigwell, 2000).

In my view a shift to a 'community of practice' metaphor for teaching and learning has the potential to enable this. If we understand how a community can change - then we can begin the task of preparing graduates as transformative (ie reflective and critical) citizens of those communities. Literature relating to communities of practice suggests this transformation occurs in various ways. Learning across activities and 'communities', in combination with learning within their specific community allows community members to form new identities and acquire new forms of knowledge, which enable professional cultures to change. I have argued elsewhere that individuals develop and change their identities as they appropriate ways of 'talking' (ie meanings, values etc) inherent in different communities (Stonyer, 2002b). Meppem (2000) maintains that from a 'discursive community' it is possible for institutional structures and processes to emerge which are capable of reformulating strategy, processes and learning.

For pedagogy, this requires us to continue to find ways to encourage transdisciplinary and methodological pluralism (a result of working across communities) into our teaching and learning. Crofton (2001) writes that as our social, technological, economic and ecological systems have grown more complex the demand for technological and organizational expertise has increased – 'specialists of the general' are needed to deal with the complexity of the problems and tasks faced by engineering. Holt (2002) extends this in his argument that engineering needs to begin to attract people whose primary concerns are the 'central principles of human affairs by which we choose to live our lives and guide our organizations'. There are a number of themes to be explored around this, but the most critical is to reframe the engineer from problem solver – to a problem architect. I particularly like this term– problem architect (borrowed from Orr I think) – because for me, it generates very quickly the creation of a 3d space for community imaged around/about 'the problem'.

Transformation of the practice, direction and development of the community also occurs as experts of a community respond to novel problems (Billet, 2001). As engineers when trying to handle one situation, a novel situation, we attempt to make use of what we have learned earlier in another situation. Novices through 'informal yet structured', and 'experiential yet social' learning situations in the community learn the skills and practices of working to solve 'novel problems'. Marton and Trigwell (2000, p5) argue that in preparing students for a future which will have unknown, novel problems, the nature of variation in their education is of decisive importance:

> If you want your students to become capable of handling a limited number of types of problems with varying parameters, you can let them practise those problems with varying parameters. If you want them to structure, define and solve problems they have never seen, you have to let them face and deal with novel problems. If you know exactly what problems they are going to encounter, you might let them deal with those problems; if you don't know what problems they are going to encounter, you have to let them deal with different problems.

Unfortunately, they don't tell us how different these problems have to be!

Discussion

The journey outlined in this paper reflects on the distinctive features and characteristics of engineering education which have delivered us to this 'watershed' in engineering education where commentators are beginning to see again, after initial welcoming in of the 'knowledge age', the dominant economic imperatives which seem to subjugate every other discursive voice. Sustainabilility, because it is defined across many discursive fields, holds open discursive spaces in which these contestations for power and meaning can be seen. These spaces allow us to ask the questions: What truly sustains us? Why? And how do we know?

What are we to sustain above all else? Why? And how may we do so? (Davison, 2001). In this paper, I have attempted to outline the architecture of a new discursive space in which another engineering education might be 'recreated'. These spaces attempt to recognise and respond to the tensions present in contemporary engineering education:

- between seizing the new opportunities to develop a powerful voice in the realm of decision making and continuing on in unashamed technical and technological excellence and innovation;
- between preparing graduates as transformative citizens of engineering (and ultimately society) and the discursive construction of the graduate as an immediately employable person fitted into an economically defined system;
- between the normative voice of engineering with its business as usual approaches and the 'other' voices speaking of sustainability.

Endnote

1. See Guile (2001) for a discussion regarding this debate where for example, Bell (1973) stresses that scientific knowledge is most important; Drucker (1993) appeals to tacit knowledge, Reich (1991) maintains a combination of scientific and tacit knowledge

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Acknowledgements

This paper marks a signpost in a journey towards finding a framework for understanding how higher education, and specifically engineering education, can respond to the challenge of sustainability to institutional pedagogical and epistemological traditions.

Gaining of Sustainability Consciousness in Engineering Curriculum through Materials Education

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Abstract: *Samuel (1991) in identifying problems associated with engineering education observed that the product of engineering education does not have an identifiable entity. Unlike professions such as medicine, law or accountancy it is difficult to associate the work of professional engineers with a defined discourse. However the perceptions of professional engineers as occupations that concern themselves with productive processes and wealth creations are increasingly augmented by views of engineering profession as one that is also concerned with environmental issues. This paper takes the view that commitment to sustainability of the end process of engineering work must serve as the ideological core of the engineering profession and therefore issues of sustainability provide the framework for engineering education. One way of enhancing the education of sustainability in engineering curricula is to raise sustainability issues in areas of engineering science. Another way is to integrate engineering subjects through service subject and weave sustainability issues as an aspect of engineering life. This paper takes the view that students' sustainability consciousness can be raised through service subject such as materials.*

Keywords: *Sustainability of engineering education*

Introduction

The notions that the practice of engineering as the means for wealth creation and economic growth have not provided an adequate perception of engineering profession as one that is socially responsible. The positivist orientation of engineering education is partly to blame. This was recognized by reports presented by UNESCO (1968, 1970) over thirty years ago. These reports argued that if environmental issues are not placed as the focus of engineering practice then the engineering profession faces being marginalised. Bella (1987) has suggested that the engineering profession has been marginalized because it lost community trust due to the perception that the engineering profession was responsible for many of the harmful side effects as a result of development and the implementation of new technologies.

Collins, Ghey and Mills [1989, p.88], suggested that sensitivity to the environmental consequences of technology, in the course of engineering practice, is essential if the profession is to gain the social trust. Environmental consciousness as the lynchpin of engineering workplace discourse is essential to regaining the public trust and strengthening the professional status of engineering. The report *Our Common Future* (World Commission for Environment and Development (WCED), 1987), in its conclusion, suggested that the focus of engineering practice must lie in sustainable development. If the professional work is one which deals with environmental problems, then the engineering educational discourses therefore need to have a pronounced environmental emphasis.

The scientific and technical core (including engineering design), in engineering education, must therefore incorporate themes such as ecology, ecosystems, and natural resources, to facilitate sustainable solutions to problems of technology. Placing environmental (and sustainability) issues, as ideological cores of engineering educational discourses, is essential to the development of engineering awareness. This has been recognized by the Industry Commission [1995], which suggested that an environmental focus of engineering education would improve the technological literacy of professional engineers because it carried with it the implicit understanding of liability and long-term economic viability of engineering practice, and also recognised the fact that technical solutions can only provide numerical answers to a complex situation. Constraints imposed by environmental sustainability allows greater emphasis, in engineering education, to be placed on comparative technologies as tools for choosing most appropriate designs or manufacturing routes which will minimize environmental and social impacts.

The professional engineer in technical practice is an initiator, implementer and restrainer of technology. It is through the last role that the professional engineer has an essential role as the guardian and the protector of society from the side effects of the application of unsuitable technologies. Environmental and ecological consciousness provides the engineering profession with a value system that can underpin ethical practice. Even in economic terms the environmental function of engineering practice makes sense. Deleterious side effects of technologies lead to closure of productive processes and loss of investment.

Environmental literacy focuses professional engineering into risk management. Side effects such as acid rain, creation of toxic dumps, and poor disposal of toxic wastes are no longer politically, socially, economically and environmentally acceptable. A holistic rather than just technical emphasis on environmental education in engineering is required if it is to provide engineering graduates with adequate knowledge basis to address environmental issues that are encountered in the course of engineering work. Hardy [1992, p.560-561] in observing the shift in engineering workplace discourses to greater environmental focus, suggested that in meeting these challenges, the engineering curriculum needs to be anchored by four contexts. These are:

- <u>Technology.</u> The context that concerns itself with the technical nature and solutions of engineering practice;
- <u>Law</u>. The legal constraints imposed by the society to protect environment that limits the technical options proposed by professional engineers. Understanding of law provides professional engineers with appreciation of the sensitivity with which the society views application of technology;
- <u>Motivation</u>. Professional engineers are concerned with the organization of work to ensure the success of the engineering enterprise. Professional engineers need to be acquainted with the ways of motivating people for positive action, knowledge of market forces, and the way people are motivated in their choice of selecting environmentally friendly products. The environmentally anchored application of social sciences focuses the profession into a community welfare perspective when proposing a particular engineering solution; and

- Accountability. All engineering decisions need to be based on environmental considerations. Given the fact that these involve the interplay of complex variables, such engineering decisions constitute the basis of reflective practice.

Environmental and Sustainable Education in Engineering

The need for addressing environmental issues in engineering education was identified in Britain in the early 1980's. The Engineering Council (1983) called for the re-aligning of engineering curricula to the goals of environmental sustainability. The "Agenda 21" document issued by the United Nations Conference on Environment redefined the practice of engineering from economic to sustainable development, and therefore, by implication, suggested that educational discourses in engineering ought also to place greater focus on sustainability (Thom, 1998). The rhetoric of the engineering profession demands greater social and multidisciplinary awareness, of the profession, in seeking environmentally sustainable solutions, a view shared by the Review into Engineering Education in Australia which clearly stated, in its introduction (Johnson, 1996), that engineering discourses will, in the future, be more multidisciplinary, requiring greater environmental sensitivity and awareness.

An engineering curriculum underpinned by environmental considerations is not new. The undergraduate engineering curriculum at the more respected universities in Brazil positioned environmental issues at the centre of their engineering courses in the 1980's (Bauer 1987). Engineering science subjects dealt with the principles of conservation of mass, energy and momentum in engineering processes and their applications to problems concerned with the environment. Environmental issues can also serve as a useful platform for problem-based learning (PBL), in which thermodynamic laws can be used to illustrate the inevitable side effects of engineering outcomes. Engineering education with an emphasis on environmental discourses is likely to enhance, in the public eye, the professional standing of the engineering profession. This was also the opinion of the Review of Engineering Education in Australia which recognized that interfacing between community and technology was an essential function of the profession [Johnson, 1996]. The ability to apply knowledge on the basis of environmental considerations, especially in health and safety, was seen in the workplace as a positive attribute of a professional engineer (Kletz, 1984). He pointed out that chemical engineers, for example, in the course of their work, will never use most of the knowledge they acquired at university, but they will, in the course of their work, have to make decisions on the basis of the environment and health and safety.

Role of Materials Education in Engineering Curriculum

Knowledge of materials represents the "physicality" of the engineering product. It is the three dimensional outcome of engineering work and its success depends on whether the design is fulfilled by the right selection of materials and the ability to produce the product with the selected materials. In terms of engineering outcomes, then knowledge of materials is empowering.

However, like engineering design, materials subjects can also integrate engineering knowledge and therefore can be a focus for the development of ideological position of professional engineering education. At Victoria University, the position I take is one of environmental responsibility. Materials properties and selection are placed in the framework of energy use. For instance energy flows provide a template through which materials knowledge connected to professional engineering practice. The material courses are structured in a way to address three major issues. These are:

1. Will the materials do the job? The issues that are of concern are mechanical and physical properties.
2. Are the materials durable? Time dependent properties such as corrosion and fatigue are addressed.
3. Do these materials affect our environment? This can be examined through the greenhouse effect on the environment and four areas of energy consumption are considered. These are:
   - Energy requirements to produce the material;
   - Energy requirements to fabricate products with the chosen material;
   - Energy requirements in use. In transportation, for instance, properties such as specific strength are of issue. Durability of material also affects the energy balance; and
   - Energy requirements for recycling or re-usage of materials.

Energy and materials integrates knowledge gained in engineering sciences and provides a focus for a critical analysis of manufacturing, engineering design, product use and recycling with a sustainable objective, outlined in Figure 1.

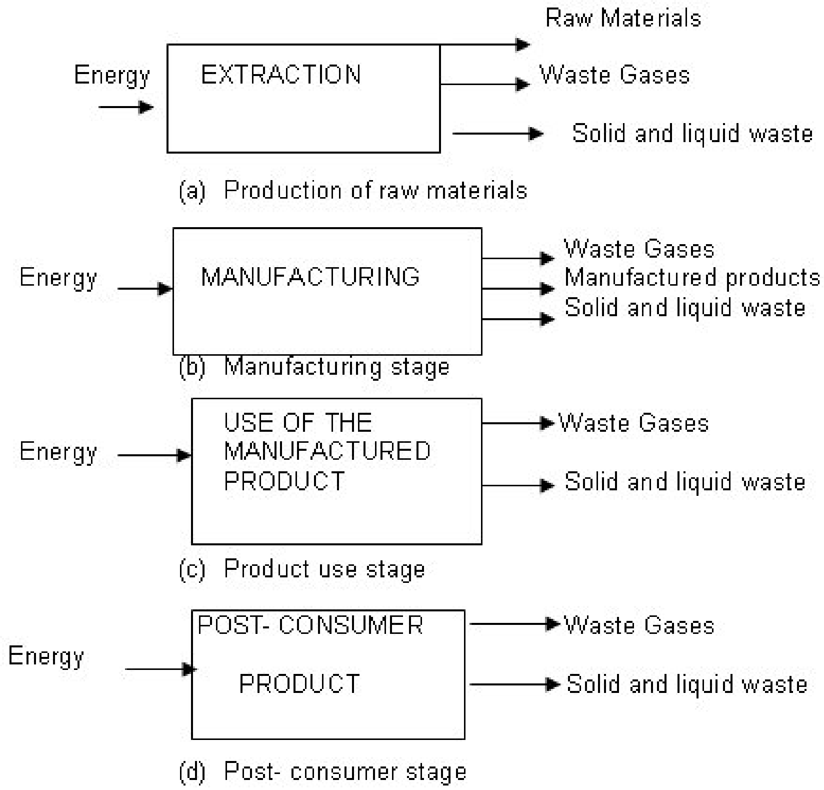

Figure 1: Engineering processes expressed through by environmental perspectives.

The discrete steps, shown in Figure 1, consist of: raw material production, manufacturing with the raw materials, energy consumption of the product, and energy consumption of the discarded (post-consumer) product. Each step is subject to engineering analysis in a form of mass and energy audit, and the integration of these steps then constitutes a life cycle analysis, based on the conservation of energy and mass of the whole productive process. Through this life cycle analysis the full picture of technical engineering emerges in the form of an engineering audit that is based on energy and mass consumption. Production of waste and greenhouse gases can be identified through this audit and this therefore allows the calculation of the true economic cost to the community. The environmental focus of the engineering curriculum, in this author's view, will extend the intellectual dimension of the engineering student and, at the same time, is likely to produce a graduate with greater awareness of engineering and the social reality.

For example, the engineering analysis of the production of motorcars can use the model shown in Figure1. The selection of materials is based on an energy audit in the production stage of materials (Figure 1 a), through the comparisons of the effects of that the production of raw materials, such as various plastics, composites, ferrous and non-ferrous alloys and ceramic, have on the environment. The manufacturing stage creates waste and requires consumption of energy (Figure 1b); the comparisons of different manufacturing processes, each process dealing with different materials, need to be made in order to minimize material and energy loss. The engineering course then focuses on the practical aspects of engineering where the scale of an engineering enterprise is given a prominence. The energy consumed by the product itself (Figure 1c) provides the issues of design. In the case of the production of motorcars, the efficiency of the engine, transmission, the rolling friction coefficient of the tyres, the reliability and durability of the product are the essential features of technical engineering, which is underpinned by environmental considerations. The final aspect of the environmental audit concerns the product itself once its service life is exceeded (Figure 1d).

The value-added entities, such as the energy locked in the product itself, form the intellectual core of engineering issues and innovation. Questions that arise concerning this product are whether all or part of the product ought to be re-used, re-cycled with the view of either re-using the materials or recovering energy from the materials, or placed in a municipal waste dump, and these continually give rise to new engineering problems that need to be tackled that translates to reflective engineering discourse.

Discussion

The linkage between materials end environment has been well established. The European Union's Joint Research Centre at Ispra, Italy, has in its research activity placed materials technology and environment under one umbrella. It is almost impossible to think of any human productive activity that is not associated with materials and impact on the environment. It is therefore the view of this author that for engineering education to seriously address sustainability issues, there needs to be greater allocation in engineering curricula to materials subjects.

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Towards a Global Sustainability Knowledge Network

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Abstract: *Sustainability is central to engineering practice in the 21st century and therefore an essential element of engineering education. For practitioners, researchers and students relevant information on sustainability is dispersed or difficult to locate as it is generated by experts in many discipline areas not just in the traditional engineering ones. Sustainability is multi-disciplinary in nature. To meet these needs a web portal, the Sustainability Knowledge Network (SKN), has been launched, building upon the foundation of the successful Australasian Virtual Engineering Library. The SKN contains over 4000 resources and has other value adding services for its users, and these are being further developed. This network is pioneering a much of broader vision – the global Virtual Environment and Sustainable Systems Engineering Library (VESSEL). AVEL and AVEL-SKN were developed by a national consortium of partner organisations including universities, research organisations and engineering institutions, that were geographically dispersed. The successful development of these resources involved the close collaboration of engineers and librarians working as a distributed virtual team.*

Keywords: *Sustainability, innovation, subject gateways, portals,*

Introduction

The issue of sustainability is moving from the fringe to the mainstream of engineering. This shift is driven a number of factors including impending regulations, a growing awareness in industry of concepts like the triple bottom line and espoused policies of professional engineering institutions globally (e.g. Ellis, 1994; IE Aust., 2003). Engineered products, systems and infrastructure must be sustainable in both the ecological and the social sense. It is no longer sufficient to build a technically sound, cost effective system delivered on time. On the contrary, it makes good business sense to develop innovative, sustainable systems, based on emerging technologies and which incorporate ecological and societal factors.

There is a global demand for high quality information on engineering and the technological aspects of sustainable development, especially via the WWW. However, the relevant information sources are dispersed across many discipline areas and are not easy to locate and assemble. Potential users are not always aware of what networked information is available. They are sometimes confused about various resources and have difficulty in finding relevant resources. The sheer volume of information on the web is staggering. In 2002, the number of Web pages exceeded the number of people available to read them. In January 2003, Google invited Web surfers to search over 3.1 billion Web pages, while NetNames gave a figure of over 36 billion for total domains registered worldwide in the previous year.

The Sustainability Knowledge Network builds upon the earlier the Australasian Virtual Engineering Library (AVEL) to provide web-resource to assist researchers, practitioners and other professionals working in the areas of sustainability and engineering to share information and ideas on sustainability. Researchers use the Web not only to find information but also to "to maintain their identity, to engage in discussion and to circulate information" (Ballantyne and Addison, 2000). This paper outlines the development and future direction of AVEL-SKN and its emergent role as part of a proposed global network of resources in sustainability aimed at current and future engineers.

Evolution of AVEL

The Australasian Virtual Engineering Library (AVEL) was established in 1999 as part of a wider movement in Australia to develop discipline -specific, subject gateways in order to assist with the delivery and dissemination of academic information.

AVEL was designed as a gateway to quality web resources. This is achieved by having experts select resources for inclusion and by maintaining the information management disciplines of librarians, including the use of widely available thesaurus for terms, clearly developed and articulated resource selection criteria and consistency in the quality of record creation. The AVEL database contains records describing WWW resources selected for their relevance. This information is called metadata and includes both a summary of the resource, created by a librarian, and information pertaining to the location, creation and so forth for the original resource. By searching or browsing the AVEL metadata, a user can either link to that resource or extract relevant metadata. Links are regularly checked and information is updated. AVEL does not contain sources found only by trawling the WWW with an automatic robot, as is the case in other repositories. However, the quality assurance through the involvement of people in creating and maintaining the database is resource intensive.

AVEL- Sustainable Development

During 2000, the concept of a gateway focused on Sustainable Development for engineers was proposed. To avoid deflecting the core mission of AVEL, or trying to create a whole new gateway, a strategy emerged to establish AVEL-SD (AVEL-Sustainable Development) as a sub-site within the overall AVEL gateway. This allowed some sharing of resources without compromising the original AVEL. It was to be a prototype to explore a number of issues.

The AVEL-SD consortium was based on the original partner organisations with additional inputs from several of these especially the Institution of Engineers, Australia (IE Aust), the University of Queensland Library and the Distributed Systems Technology Centre (DSTC). Working closely with the IE Aust., the Institute of Professional Engineers, New Zealand (IPENZ) joined the consortium and both provided links to the World Federation of Engineering Organisations (WFEO) and United Nations Educational, Scientific and Cultural Organisation (UNESCO). Having both the peak professional bodies for engineering in Australia and NZ involved was indicative of the increased recognition of sustainable development and sustainability issues to professional practice. AVEL-SD was launched in November, 2001.

A basic business plan was developed to cover issues such as collection development and resource selection were resolved including access to materials from IE Aust and IPENZ from their environmental engineering and sustainability groups. While the trial was successful and considerable interest was raised, it was difficult to sustain both AVEL and AVEL-SD. During 2002 the Australasian Virtual Engineering Library decided to re-focus its content, redesign the user interface and strategically re-align itself to be more in keeping with this move towards incorporating sustainability principles into mainstream engineering practice.

Sustainable Knowledge Network

The Sustainability Knowledge Network, was envisaged as something more than a subject gateway or portal - a virtual place for engineers and others to "meet" and share information in many forms and media. The scope is not solely on sustainability, but the network also incorporates information on developments in core engineering disciplines (mechanical, civil, etc.), and developments in new technologies and innovations (but not just IT). This clearly reflects the AVEL origins. It has the benefit of not isolating sustainability as something new or different, but rather as part of the emerging spectrum of engineering.

The initial stage of the redevelopment involved the creation of a new web site hosted at the old AVEL domain name, as well as the migration of existing key resources already contained within the AVEL repository and the addition of new resources that focus on sustainability. In response to customer feedback the emphasis is on building a collection of freely available and reliable full-text content. Full-text papers from the Environmental Engineers Society (IEAust), CSIRO and the Academy of Science Technology and Engineering have been made available to AVEL for hosting.

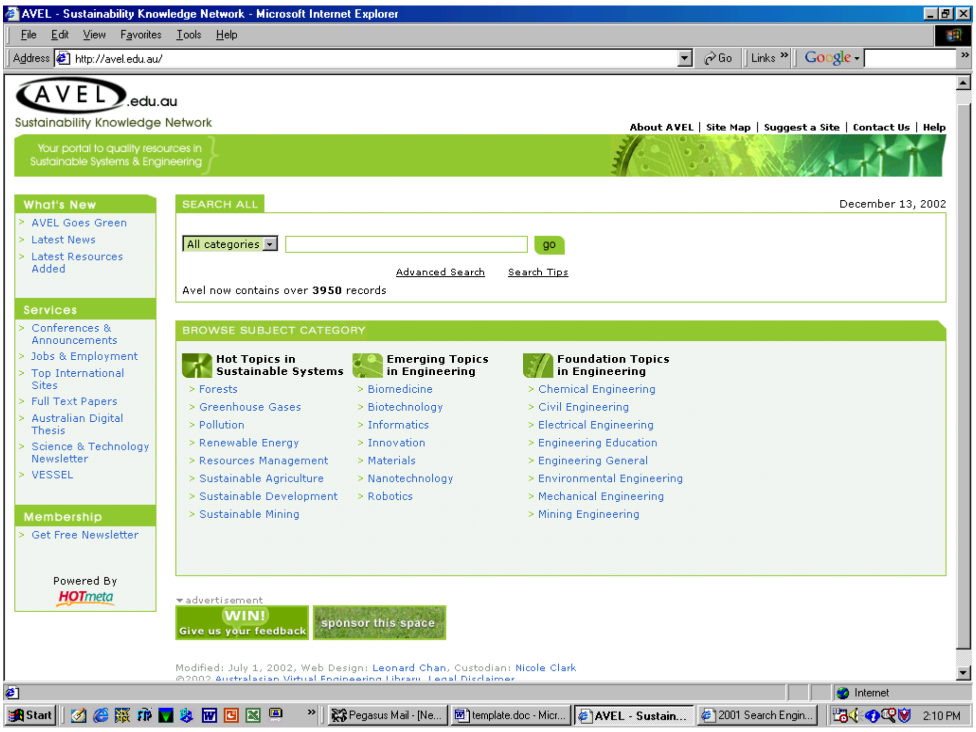

Figure 1: Sustainability Knowledge Network (avel.edu.au)

For the purposes of browsing the resources are organised into overlapping themes on the home page - Foundation Topics in Engineering, Emerging Topics in Engineering and Hot Topics in Sustainable Systems. The Foundation Topics are grouped by traditional discipline areas, i.e. chemical engineering, civil engineering and so on. The Emerging Topics include biomedicine, biotechnology, informatics, innovation, materials, nanotechnology and robotics. The Sustainable Systems section is very broad and includes forests, greenhouse gases, pollution, renewable energy, resources management, sustainable agriculture, sustainable development and sustainable mining. The existing metadata management software (HotMeta from DSTC) was upgraded and the Sustainability Knowledge Network went live in September 2002. By the end of 2002, there had been a 17% increase in traffic to the domain, and a 75% increase over the previous 12 months.

The second phase of the redevelopment which is underway will see the trial installation of metadata harvesting software. If successful this will allow the Sustainability Knowledge Network collection to be rapidly expanded. The vision is to give the user the option of choosing either records evaluated by people or automatically harvested records or both. Project partners will also have the opportunity to use HotMeta 2.0 software to directly enter metadata which adheres to the project's metadata schema into their existing web page. This will enable more accurate harvesting to occur as well as save partners time in creating separate metadata descriptions. Increasingly, subject gateways are realising that hand-created metadata is an expensive process that cannot be supported on a stand-alone basis. A metadata record for an average website can take between 20 and 30 minutes to create. While these records add value to assisting resource discovery, they must be supplemented with viable, longer-term solutions.

The third phase will enable services which promote collaboration and knowledge exchange to be added to the gateway. The types of services and functions offered by the Sustainable Knowledge Network include:

Feature	**Purpose**
Searchable database with access to full text publications	• *Access to full-text publications such as technical reports and conference papers from partners* • *Intellectual Property rights for each document captured in metadata schema*
Expertise Directory	• *A searchable and browseable online directory to facilitate multi-disciplinary knowledge transfer and partnerships*
Topic based discussion forums	• *Regular moderated discussion forums which will showcase research*
Searchable, browseable, metadata enabled links	• *Central repository of metadata enhanced WWW resources*
Conference / Events Listings	• *Centralised discovery of conferences and events as well as user-submitted events listings*
Online News	• *Links to current news in the area of sustainability*
Bulletin Board for News Postings	• *Topic-based bulletin board postings to facilitate communication and knowledge sharing*

Table 1: AVEL-SKN Features

Thus the Sustainability Knowledge Network is becoming a web space that will allow users to interact, exchange information and collaborate using a broker model. But it is also part of an ambitious global project to provide web resources on sustainability and other services to practitioners, researcher and students everywhere.

Business Model

The basic business model we are adopting has five complementary parts: (1) raise revenue via tiered member scheme based on a value proposition made to the prospective members, (2) capture new content from members and other partners as in-kind contributions, (3) conduct consultancy or project work that both contributes revenue and either additional resources or some form of technical capability of value to the Sustainability Knowledge Network, (4) sponsorship of the site via advertisements on the home page and (5) grant income on an opportunity basis.

Four grades of membership are proposed – Platinum, Gold and Silver plus Foundation members. The subscription level for each grade of membership will be staggered and the benefits and services to each grade will also be tailored accordingly. These benefits can include membership the Advisory Committee, having logos included on home page and other publicity material, free MetaEdit software, unlimited record creation (available for Events Directory, AVEL-SKN database, Expertise Directory), awareness of new projects and websites which are relevant to sustainability are publicized through a web-based newsletter and "What's New" section and discounts on web page advertisements.

The primary in-kind contribution will be new content in the form of new resource suggestions but preferably metadata. It is expected that this will be a condition of membership in the higher categories. As an incentive, members can go to a higher grade based on a combination of annual subscription and a minimum number of new resources contributed over a 12-month period. (This is a form of loyalty scheme – like frequent flyers). The goal is to have members enter their own metadata as a strategy for making the continued growth of AVEL-SKN.

Consultancies and tenders provide a source of revenue but at the cost of diverting resources from core Sustainability Knowledge Network activities. Equally they provide an opportunity to add to core Sustainability Knowledge Network capabilities. Therefore the team will take on consultancies that are either of (a) strategic importance to the project and/or (b) add a key technology, other capabilities or content to the team that will directly benefit the ongoing development of the Sustainability Knowledge Network.

Advertising from sponsors on the Sustainability Knowledge Network home page is another way of raising revenue. Only advertisements that are broadly in keeping with the vision and goals of the project will be accepted. Acceptance of potential sponsors is at the discretion of the project's Management Team.

In addition, the Sustainability Knowledge Network team is seeking grant income on an opportunity basis. These will include small to medium grants for specific sub-projects that form part of the overall the Sustainability Knowledge Network as opposed to a single large grant for the whole service. The opportunities for gaining a single large grant for the Sustainability Knowledge Network are very limited due to changes in funding priorities. Its ongoing development is therefore dependant on the generation of new sources of revenue.

VESSEL – A Global Sustainability Resource

The Sustainability Knowledge Network is the inaugural part of a global set of resources in sustainability related to engineering VESSEL or the Virtual Environment and Sustainable

Systems in Engineering Library (Rourke, 2002). VESSEL is a joint project between the Sustainability Knowledge Network and the World Federation of Engineering (WFEO). WFEO represents the world-wide engineering profession through over 80 national members, and nine international members representing regional groupings. In partnership with UATI it forms the International Council for Engineering and Technology (ICET), an umbrella organisation associated with UNESCO.

The principal emphasis of the VESSEL network will be to provide developing nations with improved access to resources that can assist in education in science, technology and engineering, at senior levels in schools and technical colleges and universities. The network will aim particularly to provide resources to teachers and lecturers, and will seek to meet the requirements identified within the developing countries.

Each of the member nations of the World Federation of Engineering Organizations (WFEO) and of the International Union of Technical Associations (UATI), will be asked to become a supplier of material, or a user and definer of needs. The world-wide network they establish will be a substantial aid to international sustainable development. The Sustainability Knowledge Network is working with a number of agencies including the Institution of Engineers Australia, the Institution of Professional Engineers, New Zealand and other members of WFEO to build up resources and to undertake a series of projects that will incrementally further the development of VESSEL.

Discussion

AVEL-SKN is a significant and growing learning resource for engineering education in Australia, NZ and beyond. Potential users include prospective engineering students while still in high school (and their teachers), undergraduates, graduate students, course-work Masters and other graduates undertaking continuing professional development. To assist these user groups and add value to the site, we are developing a series of guidelines, fact-sheets and the like that provide a overview of key concepts and directions in sustainability in relation to current or emerging engineering practice. These will be available on the home page of AVEL as stand alone information but also encourage use of the core information in the AVEL-SKN database. The initial focus is on “green design” principles. This theme will cover such issues as general principles including definitions and concepts like triple-bottom line as well as information on design of the environment, by-product synergy and life cycle analysis.

Taking this one stage further, there is the opportunity to use AVEL-SKN as a hub for national, student-led initiatives in engineering and sustainability. AVEL-SKN was never intended as a passive virtual library, but rather as an active site that encourages people to work together to both contribute to its development as well as draw knowledge from it. Such an initiative would ideally involve not just engineering students (and researchers and practitioners) but also students from other disciplines in concerned with the environment and social issues. The AVEL-SKN team offers this challenges to the AaeE community and its wider constituents.

Further, AVEL-SKN, through VESSEL, offers opportunities for international educational outreach and collaboration. In particular, the Sustainability Knowledge Network is in a position to foster new and closer links between different disciplines, working internationally and coming from quite different perspectives and with diverse information needs. It is no longer targeting a well-defined community of practice that has a common set of understandings and approaches as it did when it was the Australasian Virtual Engineering Library.

On a more pragmatic matter, gateways like the Sustainability Knowledge Network continue to provide a valuable service to a distributed, "invisible" constituency and user base, but they face a number of challenges from the next generation of Internet search engines (e.g. Google) and from the need to secure funds for continuing development and ongoing operation. These challenges present opportunities to create innovative ways to add additional value to their clients. Developments in web technology such as the OAI initiative (Hussein and Fox, 2001) increased emphasis on the development of web services architectures, changing web usage patterns and possible new models of the ownership and distribution of information in electronic form also offer opportunities for traditional gateways to morph into brokers, service providers and participatory networks rather than being simply repositories of quality information.

In addition to continuing to grow the resources base and extend value adding services to our clients through initiatives like VESSEL, there are a number of issues around how engineers and others use SKN that we plan to investigate. As engineers seem to rely upon "trusted" sources - like colleagues and tested information sources and informal networks, our aim is to provide a virtual equivalent of these trusted sources (Ellis and Haugan, 1997). Future developments will reflect this through the introduction and testing of interactive information exchange from users (similar to bulletin boards), access to expertise directories and the like. We are planning to conduct additional usability testing using an instrumented usability lab, to extend our earlier heuristic evaluation of user issues.

Conclusions

The Sustainability Knowledge Network is a new resource for engineering education at many levels – from high school to CPD. As the initial implementation of a global network, VESSEL, it has the potential to facilitate growing interaction between engineers and others around the topic of sustainability both in Australia and NZ and in our region. While it takes advantage of resources built up for the Australian Virtual Engineering Library, the future success of the SKN will depend upon the degree to which it is used, the quality and diversity of the new resources and value added features that are added and the willingness of groups to be financial and in-kind partners in it. AVEL-SKN is moving into new, largely uncharted, territory.

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Acknowledgements

The authors acknowledge the receipt of an Australian Research Council, Research Infrastructure and Equipment Grant to support this project. The financial and generous in-kind support of our foundation partners is acknowledged. The foundation partners are: The University of Queensland, Queensland University of Technology, Melbourne University, Monash University, the University of New South Wales, and the Institution of Engineers, Australia. We would like to thank the many people who have contributed to the development of AVEL and the Sustainability Knowledge Network.

In Transport the Small Picture is becoming the Big Picture

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***Abstract**: There is increasing interest in sustainable transport, e.g. walking, cycling and public transport. This is reflected in the wording of numerous recent transport and other Government strategies.*

Engineers have an important role in the implementation of these strategies in relation to cycling, including the manner in which roads are designed or maintained, and the planning of bicycle networks.

Provision for cyclists in the design of roads or new urban areas is not automatic or necessarily required, and is often not considered to be important. There has been a culture of opposition to accommodating cyclists. However, engineers need to be aware of their duty of care to all road users.

Despite this, it is evident that many traffic engineers are supportive of measures for cyclists, but they may have insufficient knowledge or experience to provide adequately for cyclists. Australia is demonstrably inexperienced in its endeavours to cater for cyclists. There have been a number of prominent failures in Australia over the years where treatments for cyclists have been installed only to be later removed due to the outcry from cyclists, the public or both.

Amongst other benefits, comprehensive engineering education has the ability to emphasise the duty of care owed to all road users, and also to provide a knowledge of the basic principles and of good practice, in relation to accommodating cyclists.

Keywords: *Traffic Engineers, Expertise, Cycling*

Introduction

The interest in sustainable transport, e.g. walking, cycling and public transport, has never been higher. Sustainable transport objectives are amongst the most important in recent Local, State and Federal transport strategies.

In general the provision of cycling facilities in Australia is only a recent undertaking. Major programs and research on cycling were initiated after the mid-70s oil crisis, and more specifically developed through the benchmark project; the Geelong Bike Plan (Geelong Bike

Plan Committee 1977). Most local and state authorities across Australia are now actively involved in the provision of cycling facilities.

The need to equip engineers with the skills to adequately provide for sustainable transport including cycling is therefore more important than ever.

Why Cycling is Receiving Greater Recognition

Cycling offers many significant benefits which have direct relevance to many issues associated with the transport system, community health and the environment. These are discussed briefly below:

Health

- *Physical Inactivity* is now recognised as one of the most significant health risks to the Australian community, second only to smoking. The health benefits of physical exercise from active transport such as cycling are substantial and well documented (National Public Health Partnership 2001, Bauman et al 2002, Roberts et al. 1995).

- *Emissions* - active transport also contributes to improved air quality as a result of reduced congestion and car emissions. Thus 'active' transport is an issue for environmental as well as individual health. Research both in Australia and overseas indicates the number of premature deaths due to smog is likely to exceed the annual road toll (Denison 2000, Kunzli et al. 2000).

- *Road Trauma* - the Commonwealth Bureau of Transport Economics has estimated the cost of road accidents at $15 billion per year. (2000). Promoting sustainable transport and particularly cycling has been shown to be an effective collision counter measure (PWWM 1994).

Environment – cycling contributes neither to noise or air pollution, and does not draw on fossil fuel reserves that produce greenhouse gases. Other benefits are conceivable such as reduced parking and road space demands, and hence reduced paved area, reduced rainfall runoff, reduced erosion etc

Equity - the bicycle has been referred to as the 'equity vehicle', as a transport mode that is available to a wide cross-section of the community - young and old, rich and poor. In comparison to motor-vehicles, bicycles can provide substantial savings in the cost of transport.

Road Congestion – increasing car ownership and use levels, and in Australia these are amongst the highest in the world (Austroads 2000). This contributes to congestion, whereas cycling is an aid to congestion on roads.

Urban Traffic Conditions – traffic practitioners are constantly engaged with improving urban amenity through reductions in local area traffic volumes, noise and speed. Increased cycling is obviously beneficial in regard to these issues.

Resources – in addition to contributing to reduced reliance on oil imports, cycling has limited infrastructural and storage space requirements and has limited energy requirements in respect of both manufacturing and use. There is mounting evidence that declining oil production appears inevitable over the next decade – it is being used faster than it can be found. (Akehurst 2002, Warren Centre 2002).

Usefulness – cycling has been long recognised as the quickest door to door mode of transport over short distances (5-10km) in urban areas, considering origin and destination walk times (Hudson 1982). Despite improvements in the management of roads and technology, this may be more accurate today than in the past due to parking and traffic congestion.

Government Policy is Recognising Cycling

Numerous recent or current transport and related policies exist across Australian Federal, State or Territorial jurisdictions, and internationally, which highlight the importance of sustainable transport and/or the promotion of cycling, to reduce congestion, reductions in greenhouse gas emissions and the like. This is demonstrated by the following excerpts:

New South Wales Government Metropolitan Transport Strategy, 'Action for Transport in Sydney (1998)' - 'Transport accounts for 14 percent of Australia's greenhouse gas emissions and is the most rapidly growing source. The growth must be slowed if Australia is to meet its international commitments to help prevent dangerous interference with the world's climate.'

'The State Government wants to encourage greater bicycle use throughout Sydney and is planning to create a citywide, interconnected bike network.'

Victorian Greenhouse Strategy (2002) – 'Given the diversity of factors influencing transport greenhouse gas emissions the government will institute a package of greenhouse gas abatement actions through the Victorian Greenhouse Strategy and other initiatives such as the Metropolitan Strategy.'

'Two new initiatives will be introduced through the Victorian greenhouse strategy……..: market testing of improved bus services and a safe walking and cycling routes to school program.'

South Australian Transport Strategy (2003) - 'South Australia, like other States, is faced with a number of serious environmental issues,…….many of which are directly attributable to the transport system.'

'Walking and cycling will be promoted as viable modes of travel, supported by well-designed infrastructure and services.'

Western Australia Transport Policy (2001) – '…greater use of bicycles will contribute to the health and well-being of the community, reduce our dependence on cars and thus improve the quality, reduce the need for costing road maintenance and expansion, and ease some of the pressure on our transport network.'

Commonwealth Government - Auslink - Towards the National Land Transport Plan Greenpaper (2003) - 'Pollution from road transport seriously affects air quality in our major cities. Petrol engined passenger cars are the principal source of road transport emissions…

…Greenhouse gas emissions in 2010 are projected to be almost 47 per cent above 1990 levels with cars accounting for 53 per cent of transport emissions. Greenhouse gas emissions from

commercial vehicles are projected to increase by around 50 per cent between 1990 and 2010 and almost 85 per cent between 1990 and 2020.
World Health Organization, European Economic Commission (2002) - 'The development of WHO Guidelines to carry out health impact assessment of transport policies on levels of walking and cycling and related health effects could form a basis to quantify these health effects and make them part of the cost-benefit/cost-effectiveness assessments of transport and land use policies at the urban level.'
In addition to the above, there are numerous other policy or strategy documents with similar statements developed by other jurisdictions (ACT US, NT DIPE, Queensland Transport, DIER).

Again, the referenced documents highlight the increasingly important role of sustainable transport and cycling, amongst key authorities both in Australia and elsewhere.

The Engineers Role in Promoting Cycling?

To achieve the policy objectives, or to promote cycling in view of the benefits outlined above, there are numerous measures that can be adopted which often fall within the area of responsibility of engineers. In general, engineers have critically important role in the provision of physical infrastructure, which includes planning, budgeting, implementation and quality control.

Effectiveness testing has suggested the following most important strategies to encourage more cycling, listed in order of merit (U-SA, 1996).

Strategy	**Score***
Bike insured against theft as part of your normal household insurance for no extra fee	7.4
Cycle paths are clear of glass and other debris	7.2
Introduction of clear maps and good signage of bike ways, routes and connecting networks	7.0
Series of convenient bicycle routes constructed to enable cyclists to take in scenery and other points of interest	6.8
Parked vehicles are restricted on bike ways during peak traffic periods	6.7
You win or gain a new bike	6.7
Motorist responsibilities in regard to cyclists are enforced	6.5
Cycling skills and safety awareness are provided in schools	6.5
Cyclists are separated from traffic on roads with speed limits greater than 50 km/h	6.4

* Probability (0 low, 10 high) that strategy will encourage more cycling.

Several of these strategies are directly related to the duties of engineers, including the manner in which roads are designed or maintained, and the planning of bicycle networks.

Duty of Care

Despite significant and increasing evidence of the need to support sustainable transport, in some respects government policy and the benefits of cycling (listed above) are almost superfluous, when considered against the basic responsibilities of traffic and transport professionals.

A duty of care exists to all road users. This is not new. Recent national and international events (e.g. HIH, September 11) and even our increasingly litigious society have not changed this, although perhaps these aspects have increased the focus on one's duty of care.

Roads are hazardous by definition. In the case of cyclists there is no 'protective outer shell', there is a significant speed differential in comparison to passenger cars, and there is a large variation in age and skill. All road users including cyclists, must receive satisfactory consideration. Engineers need to be aware of this and must be able to provide adequately for cyclists regardless of the way in which they perceive cycling.

Why the Needs of Cyclists are Ignored

Provision for cyclists in the design of roads or new urban areas is not automatic or necessarily required, and is often not considered to be important. There are many reasons for this.

It is evident that cycling has an image problem due to:
- the way cyclists are perceived on roads;
- the fact that cycling has not been seen as the 'big time' in the transport field.

Many drivers regard cyclists as having limited regard for road traffic laws. Without doubt many traffic engineers also view cyclists in this way.

Whilst there is no suggestion that cyclists are without error, a knowledge of cycling can explain many of the apparently irresponsible acts of cyclists. For instance:

- running red lights - larger intersections have insufficient inter-green periods for cyclists to safely clear these intersections, as they travel in the order of half the speed of other traffic in urban areas. On side roads many cyclists are unable to actuate traffic signals as the signals directed at the main road generally rest on green and cyclists may have non-ferrous bikes which do not actuate the signals or have a lack of knowledge on how to position their bike to actuate the signals etc

- riding centrally in traffic lanes – it is well known amongst bicycle planning practitioners that cyclists can comfortably share a lane with passenger cars when the lane width is at least 4.0m, and that cyclists effectively control a lane (i.e. are unable to be passed within the lane) when it is less than about 3.2m. Between these widths, cyclists are generally regarded as being at risk, due to vehicles squeezing past cyclists within the lane when the width is insufficient. Many cyclists understand this and take defensive action by 'claiming the lane' i.e. by positioning themselves centrally in the kerbside lane.

Other reasons why cycling receives less attention may include:

- low cyclist numbers in Australia;

- technical aspects of providing for cyclists may be regarded as less interesting to engineers in comparison to calculating motor vehicle queue lengths;

- accommodating large vehicle swept paths etc.;

- dealings with semi-political and sometimes aggressive bicycle advocacy groups.

Low cyclist numbers are obviously of no assistance in the face of the massive demand for road space, or the problems associated with land acquisition which may be required in order to accommodate the additional width to accommodate cyclists in a road carriageway.

There is no equivalent for cyclists, to the Disability Discrimination Act which establishes a statutory obligation to provide for people with disabilities.

These factors all contribute to another problem in the transport profession that is widely discussed. There has been a culture of opposition to accommodating cyclists. This is also a concern for other forms of sustainable transport but generally not to the same extent. It is arguably a greater problem with more senior members of the profession, who are said to have 'grown up with the motor vehicle'.

In view of the sections above, often only government policy and a duty of care will ensure consideration of cyclists. Unfortunately, there are too many examples of supportive governments failing to back initiatives for cyclists when the costs become too large or the issues become too great, leaving just a duty of care as the primary reason to provide for cyclists.

Influencing engineers as to their responsibilities to all road users is therefore extremely important.

Lack of Knowledge of Cycling

It is evident that many traffic practitioners are supportive of measures for cyclists but have insufficient knowledge or experience to provide adequately for cyclists.

Some common factors that reflect a lack of knowledge and experience include:

- reinventing the wheel, e.g. introducing European style treatments but making the same (now well recognised) mistakes as some European countries in past years;

- use of census data in strategic transport planning – in South Australia at least, during the last four census days, the weather was particularly poor and as a result cycling was almost non-existent on those days;

- constructing paths as footpaths rather than 'bicycle roads', e.g. with abrupt corners rather than smooth curves;

- constructing a commuter route that is circuitous and hence slow, where in fact time is likely to be a critical factor in terms of a cyclist's route preference;

- intersection design and line-marking that ignores the needs of cyclists by forcing multiple stops, or worse, by discontinuing the cycling facilities that exist on the approach roads.

There have been a number of prominent failures in Australia over the years where treatments have been installed only to be later removed due to the outcry from cyclists, the public or both. The most disappointing aspect about this is that in some cases the practitioners themselves have become somewhat disillusioned with providing for cyclists.

In addition to a lack of knowledge of cycling, it is evident that the knowledge of cyclists' needs and provisions is sometimes not valued by decision makers, e.g. engineering managers. Also, it appears to surprise people at times, that in bicycle planning and engineering, there is good and bad practice, and that detailed guidelines and reference books exist.

It is important to understand that unlike European countries, Australia's interest in cycling is only recent. The first national conference on bicycle planning and engineering was held in 1986 in Newcastle. [Since then national or international conferences have been held on just three occasions (Melbourne, 1992; Fremantle, 1996; Adelaide, 1999) which is probably insufficient for networking, dissemination of recent research, amongst other issues].

'Bicycle agencies', which often reside in state road authorities, came to exist in a majority of states only during the 1990's.

As a country we are demonstrably inexperienced in our endeavours to cater for cyclists.

Bicycle agencies, which generally reside within state road authorities, have fallen in and out of favour over the years, and therefore have not enjoyed continuity, and are unable to pass on knowledge and experience as a consequence. In parallel to this, practitioners, both in road authorities and amongst consultants, have generally experienced a short professional life in cycling. For instance, notably, the stalwarts of bicycle planning and engineering from Victoria in the 1980's, and from Western Australia in the early 1990's, have generally moved on, and have little or no involvement in bicycle planning and engineering now.

This is quite possibly due to the 'rugged' nature of the work, resulting from intense criticism or inspection by bicycle advocates, politicians and senior management, when new programs, or unknown quality treatments, are either planned or implemented.

More specifically, the rugged nature of the work is due to the many problems in retrofitting an established road environment under heavy demand, with provisions for one mode of transport with limited numbers (which many believe is a result of the lack of provision). It is expensive and obviously the budget for an emerging transport mode is often limited. One is tempted to 'do it on the cheap' in these circumstances and as such there is significant potential for mistakes.

The risks of introducing new or innovative treatments are sometimes significant, and hence are also a factor.

There has been much discussion on the effects of down sizing in the 1990's. In cycling matters, the loss of staff has resulted in the establishment of a void in knowledge in some agencies during different periods.

Comprehensive engineering education on these matters has the ability to:

- provide a knowledge of the basic principles for every traffic practitioner;

- provide a knowledge of good practice that will avoid common and sometimes appalling errors;

- influence road planning where cyclists' needs will be accommodated in the road design, in an appropriate way;

- circumvent the impact of changing workplace environments;

- provide senior engineering managers with an appreciation of the impacts of decisions on cycling, in a similar manner to those associated with other transport modes.

Engineering education requirements, and curriculum development issues, in relation to cycling, have been outlined by van den Dool (2003).

Conclusion

To have relevance, transport professionals need to lead from the front. It is not possible to plan or design roads today without a good appreciation of the characteristics and needs of the various road users. In consideration of the duty of care of transport professionals to the various road users, nothing else seems appropriate.

Failing to embrace change in this regard is not without 'risk' as to the traditional role of transport engineers. For instance, in the past, the principal Quebec (Canada) bicycle advocacy organisation wrote the local bicycle engineering design guidelines, provided most of the planning and engineering expertise for cycling facilities and importantly, enjoyed considerable support from politicians. As a consequence it strongly influenced many road design and planning decisions.

There are many reasons to support cycling. The increasing support for sustainable transport and cycling by Governments, needs to be recognised by the educators of engineers. This must surely mean that those going on to practice in the transport field specifically, need to be more knowledgeable on cycling. Similarly, engineers need to be favourably disposed to providing for cyclists despite the low numbers, and even despite the lack of support amongst some in the community.

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Acknowledgements

I gratefully acknowledge the assistance and encouragement, in the preparation of this paper, provided by Paul Magarey, Acting Chair, Australian Bicycle Council, Department of Transport and Regional Services; John Grinsell, NSW Roads & Traffic Authority; Dick van den Dool, Jamieson Foley Traffic & Transport Pty Ltd; Peter Good; and Peter Watts, Transport SA.

Integrating Design into an Alternative Engineering Curriculum

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Abstract: *Traditionally, engineering design has been considered to be the core of engineering education. This has been reiterated more recently with the joining of design curriculum to the initial formation of graduate capabilities by making explicit what has often been implicit in design papers all along – teamwork, problem solving, time constraints, interpretation of client and engineering constraints, aesthetics of design etc. More recently, alternative engineering curriculum have been developed responding to both interdisciplinary developments in engineering and redefinition of engineering roles away from traditional discipline specialisation. The core requirement of design remains both from the perspective of validation of 'new' or 'hybrid' engineering degrees and the ability to bring 'real-world' scenarios inside the classroom. This paper outlines how this challenge to remain 'true' to engineering's traditional focus of design education particularly for mechanical engineers, while working with an over-full 'hybrid' curriculum, is being resolved in the Bachelor of Engineering programme at Auckland University of Technology. Feedback and advice are sought in order to help deliver significant student learning experience.*

Keywords: *Design, methodology, curriculum development*

Introduction

Engineering design continues to be an emerging discipline (Samuel & Weir, 2000). Most learning institutions offering courses in engineering have grappled with the nature of engineering design experience to be offered to students with varying outcomes. The history and structure of design teaching in traditional mechanical engineering degrees accounts for a significant amount of the overall teaching content, for example, design accounts for 15% of overall teaching content in University of Auckland mechanical engineering, and there is a design class in every semester of the undergraduate degree course (Siedel et al, 2002). As other alternative (to traditional) undergraduate degrees have emerged the focus of design as a traditional core competency has remained. These 'new' degrees and hybrid disciplines have required a rethink of precisely how to teach design in relation to their revised curriculum content and more over, exactly what design enables a graduate engineer to learn. For instance, the recent BE in Mechatronics at Deakin University acknowledges the fundamental requirement of design but it is only incorporated as a core unit at the fourth level.

Engineering design is widely understood as providing the integration of theoretical knowledge, skills and practical elements (such as engineering standards and realistic constraints such as manufacturability) of an undergraduate degree. More latterly, design has been seen as providing space for graduate attributes to be developed (eg Messer, 2001). Increasingly, design projects are group endeavours where the development of graduate capabilities in teamwork and communication are incorporated as part of the 'project' outcomes (Hadgraft & Prpic, 2002). In a similar way, design has become the focus for the inclusion of sustainability, environmental, economic, political social and ethical issues within learning outcomes. In fact, we can do everything through design projects!!

At the professional level, the inclusion of design in an undergraduate programme in relationship to graduate competencies, technical content and demonstration of professional skills is required for accreditation of an engineering degree. The Institute of Professional Engineers of New Zealand (IPENZ) state 'the curriculum shall include engineering synthesis or design and related project work'. Further, core unit requirements for membership specify graduate attributes in the areas of planning/design, communication and ethics amongst others.

Bachelor of Engineering Degree at Auckland University of Technology (AUT)

The mechanical engineering degree at AUT was established as a manufacturing and production engineering degree; that is, the focus was not a traditional mechanical degree. The degree offers specialties in the growing areas of manufacturing management, automation and control systems. The proposed graduate employment roles are oriented towards project engineer and/or production engineer rather than design engineer.

The programme has adopted an approach to curriculum design that emphasises the developmental nature of the attributes necessary for good designers on one hand, and the variation of our unique graduate profile in relation to a 'traditional' mechanical engineering graduate on the other. Hence, aspects of design are integrated through our programme, not simply in the 'design project' format, but throughout a number of papers at different levels as in Table 1. Features of the degree programme relating to design include:

Year	Features of academic programme
First	Engineering computing; engineering science principles; engineering mathematics; communications and graphics
Second	Engineering science principles, manufacturing technology, engineering modelling, projects (eg design and build self propelled vehicle)
Third	Engineering economics; systems analysis, mechatronics and automation, projects
Fourth	Design methodology; industrial project in conjunction with work placement; ethics and sustainability; advanced manufacturing technology; OM

Table 1: Design–related components in AUT Bachelor of Engineering curriculum

Design Pedagogy

The pedagogical approach to design aims to provide a 'real-world' learning environment in which students can integrate knowledge and which provides opportunities for deeper and more meaningful learning to occur through a guided learning experience. Our enthusiasm for real-world learning has, to some extent, been balanced with the realities of our real-world classrooms as indicated in the following: capabilities, lack of 'engineering' experience, learning styles.

Capabilities

Firstly, our experience suggests the development of graduate capabilities must be addressed across the curriculum, not simply for instance, in the isolation of a single 'group' project. We have previously discussed the integrated approach (both in teaching and learning approaches and assessment) adopted in the programme to develop group or team work capabilities (Stonyer, Dodd et al, 2001). This approach begins in informal tutorial groups in the first year, continuing through to design project challenge groups in latter years.

Engineering experience

Secondly, many design texts refer to the elusive (for undergraduate students in the main) work of 'experience and heuristics' (Samuel & Weir, 2000) in the process of design. For most of our students with limited exposure to the manufacturing/production engineering industry, 'experience' is severely limited. This requires us as educators to reflect on how and what we teach in engineering design. It also challenges us as educators to focus on describing 'what is going on in our heads' when we are doing design – that is making the implicit of experience and heuristics explicit where possible.

This approach differs from the more 'traditional' design project scenario based on either project-assisted approaches (viz the 'old' approach) or student-centered problem based learning pedagogy (viz the 'new' approach) (Hendy & Hadgraft, 2002, p133). While supportive of a problem based learning approach, it does have disadvantages relating to:

- removing the need for students to be 'pre-trained'- an outcome of the project-assisted approaches (ibid);
- weaker specialist knowledge and
- weaker technical methodology (Kjersdam & Enemark 1994)

Often, it is precisely this 'pre-training' phase that provides both specialist knowledge and methodological rigour. 'Pre-training' to achieve these goals may well be considered a necessity by educators given the time constraints of an engineering degree and increasing pressures of meeting the vast range of learning outcomes to be met. Part of our role, therefore, is to engage students in a variety of learning modes, which facilitate understanding the methodology of design and how to identify and utilise existing processes/procedures available in engineering, while at the same time accommodating their limited experience.

Learning Styles

Thirdly, the focus in tertiary education over the last 10 years on 'student-centered learning' requires us as educators to recognise students enter our classrooms with a range of learning styles (Cropley, 2001). Hendy & Hadgraft (op cit) found that students preferred learning styles in a specific problem based learning context, were predominantly 'seeks solutions to problems' and 'seeks intellectual comprehension'. However, not all were analytical learners – a finding which suggests that students may need learning contexts which focus on the skills of analysis and synthesis essential in the solution of design problems. Consequently teaching methods particularly in relation to design should accommodate a range of learning styles by initially guiding students to strategies, resources and learning materials which support the generation of realistic solutions to engineering problems and then to problems in which the process and solution are totally student driven.

Design Methodology

The paper 'Design Methodology' in the fourth year of the degree is part of an overall approach to the development of design skills and capabilities. It covers the process of design as a problem-solving, decision making, creative and optimising activity. Course content includes design philosophy, methodology and procedures. It deals with the creation of solutions to fulfil an engineering need, and is a synthesis of material studied in earlier modules (eg. design against failure, materials selection, fatigue, etc.). Assessment items specifically address the engineering genres of report writing, case study presentations (both oral and written including posters) and design development review.

The paper seeks to demonstrate how engineers solve problems through design methodology, not as a preset series of steps, but rather as a methodological approach – a 'roadmap' (Dym & Little, 2000, p22) - incorporating contemporary and appropriate tools available for the solution of engineering problems. Hence, the paper specifically identifies and addresses the weakness in technical methodology identified in some student centered learning approaches.

Samuels and Weir (2002, p293) present this roadmap in the form of an acyclic flow diagram (see figure 1). This approach aims to guide the student through the 'forest of complex choices' and provide strategies for selecting 'the excellent from the merely good' (Ashby, 1999, p2).

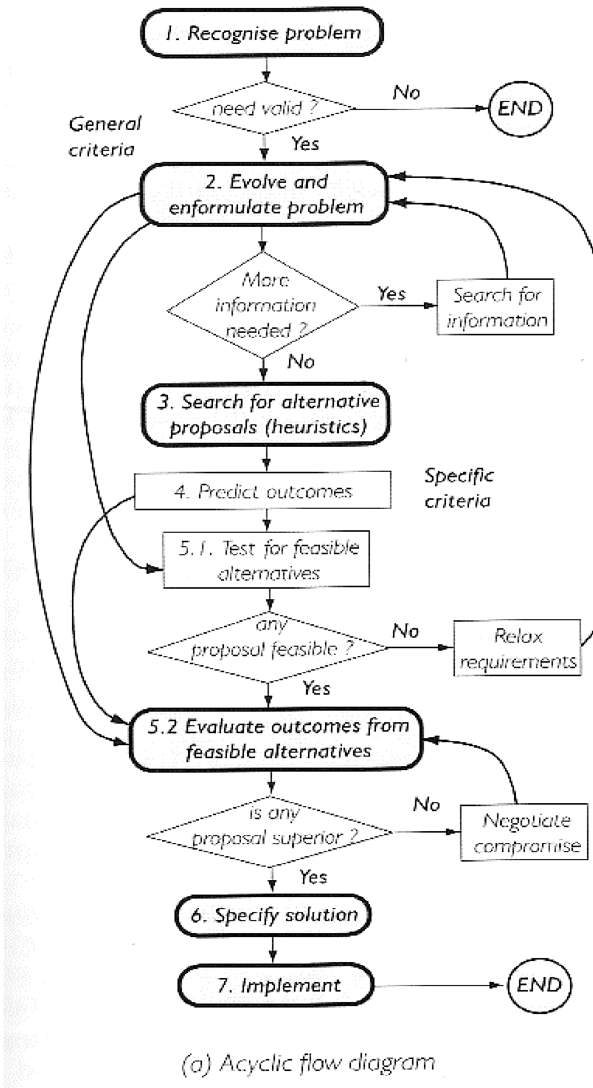

Figure 1: Design Methodology: Acyclic flow diagram from Samuel & Weir, 2000, p 293

The key concepts addressed in the paper, Design Methodology, are outlined in the following table:

Key Concepts addressed in paper	Selection of elements covered
Understanding Design	Design process overview; questioning and Fermi techniques; resolving conflict
Design process	Evolution and formulation, objective trees, weighted objectives; acyclic versus linear-serial design process diagrams
Managing design process	Scoping, spending, scheduling, function/means trees
	Design space, morphological charts, prototyping, modelling, ethics, environmental aspects

Material selection in design	Function, material, shape and process, limits, indices, standards
Design against Failure	Including risk management, OSH
Case studies	Various including whisker pole, compression spring

Table 2: Key concepts addressed in Design Methodology

Case Studies

Case studies are used throughout the paper. The range of case studies has been selected to make the applied learning of design methodology authentic (Boykiw, 2002). Case studies are not 'student initiated' however, they have been designed to challenge students to learn new concepts and not just apply knowledge already learned (Hendy & Hadgraft, 2002). In initial case studies there is a need to demonstrate the joining of theory to practice and guide students to explore other aspects of the design context (eg ethics, financial considerations, personal and professional judgement, the effect of time constraints). As the paper progresses through these case studies, autonomy in learning and the tools of the design process are progressively handed over to the student.

A typical case study in the materials selection area involves the selection of an appropriate material for a whisker pole as used on an Americas Cup yacht (ref Appendix 1). This particular case study is fairly structured with instruction in related design theory (ie columns) included in the study. The relatively new approach to material selection (Ashby, 1999) making use of design optimizing parameters or material indices is also included and enables students with limited detail knowledge of material properties and behaviour to gain an understanding of the basic material selection process. The approach offered by Ashby (ibid) seeks to establish a performance index for any given application which will allow the selection of an appropriate material based on material selection charts. These plot various material attributes against each other, and material indices plot as contours on these. In Appendix 3 a summary of the material selection process and a typical selection chart are included.

A later case study requires the design of a compression spring in a pressure relief valve (ref Appendix 2). By the time students reach this case study it is anticipated they have the skills and abilities to determine both process and detail design outcomes relating to the design of the compression spring. Therefore, the case study while referring students to a selection of appropriate design texts and data relating to the design, adopts a completely student centred research/learning process with little 'teaching' intervention, although the lecturer is still available in a consultative role.

Student feedback

The design methodology paper was offered for the first time in 2002, and was generally well received by students. Student evaluation of the paper showed that 100% considered that it stimulated ongoing learning. 86% were satisfied with the interest and challenge generated, and confirmed the usefulness of resource materials (textbooks, handouts, paper guides, etc). This and other student feedback indicates little module modification is necessary at this time from a learner perspective. However, a more inclusive overall analysis of project work versus formal assessment (Mills, 2002) would give a better picture of need for change, by using year to year / module to module comparisons. Proposals for modification would then be submitted to the programme Board of Studies for approval.

Discussion

Teaching design is both problematic and essential. The approach identified above responds to the following:

- The essential nature of design as a core capability of the engineer,
- The requirements of design for accreditation of an engineering degree
- The locus of design as a place of integration of theory and practice in engineering
- The 'real-world' context for teaching and learning 'authentic' engineering
- The 'real-world' context for the initial formation of graduate attributes and capabilities
- The importance of teaching methods accommodating a range of learning styles.

We have attempted to define, given the constraints of time and space within an already overfull curriculum and 'non-traditional' graduate profile, a way of balancing: firstly, the need for design; and secondly, questions relating to 'what form?' does design take for this engineer. It will be apparent that the curriculum and this paper specifically address the need for a fundamental grounding in the principles of design methodology. Our difficulty is in finding space for the iterative cycles of design which are essential in design for manufacturing/production contexts. While the Department of Mechanical Engineering at AUT is experienced in teaching design, the approach outlined in this paper is relatively new, and your feedback and advice based on your own learning in developing curriculum for 'new' and 'hybrid' disciplines of engineering is welcome. Given the ever changing context of engineering education, the challenge of maximising design environments to deliver significant learning experiences in, and as close as we can approximate, 'real-world' engineering in our classrooms will continue.

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Appendix 1

DESIGN METHODOLOGY

Project B MATERIAL FOR WHISKER POLE

Problem Statement

Racing yacht designer Tamberlain designs an Americas Cup boat. When using a spinnaker, the spinnaker pole is held in place and can be adjusted fore (forward) and aft (backward) with a brace (high strength rope), which leads from the outer end of the pole, back to a winch at the stern (rear) of the yacht. Two other ropes control the height of the pole, which has its inner end attached to a slide on the mast. Spinnakers are the large colourful sails used for off the wind sailing. ie. the wind is coming from the beam (side) or aft (rear) of the yacht.

When the wind moves forward of the beam, the pole is eased forward to provide the right angle of attack for the sail and to keep it filling and driving the yacht forward. In order to prevent the pole hitting the forestay (wire rigging from mast to bow), and to give the brace a more favourable angle to the spinnaker pole, a second pole known as a whisker pole is used. This is much shorter than the spinnaker pole. It is also attached to the mast at its inner end, and juts out at right angles to the boat, with the brace passing through its outer end. It is not supported in any other way and its ends can be considered as pinned. The pole is to be of minimum mass, and must support the compressive loading imposed by the brace without buckling. Ideally it should have as small a cross section as possible. It must be able to withstand knocks and bumps imposed during use. Cost should also be considered, even though this is for a large budget campaign.

Determine suitable material indices and select candidate materials which will satisfy the above requirements. Justify your choice(s).

Appendix 2

DESIGN METHODOLOGY

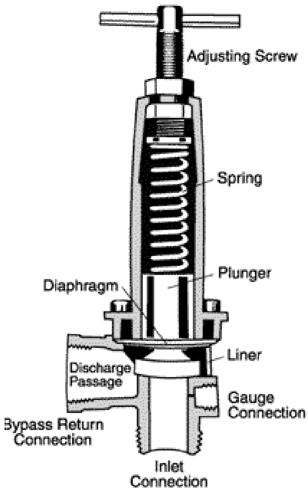
Project E HELICAL SPRING FOR PRESSURE RELIEF VALVE

<u>Problem Statement</u>

A helical spring with squared and ground ends is to be used in an adjustable pressure relief valve. Operational and dimensional criteria determine that the spring must exert a force of 270 N at a length not exceeding 62.5 mm and 470 N at a length of 50 mm.

The spring must fit within a tube of 37.5 mm inside diameter, and the loading can be assumed to be essentially static (ie. the valve is only expected to operate in an emergency).

Determine a satisfactory design, specifying wire diameter d, coil; diameter D, and number of coils, N. The material for the spring will be ASTM 229 wire without presetting.



1. Assume a clash allowance of 10% (ie. spring will have an allowance of 0.1D between maximum load condition and chock or solid condition).
2. There are no unfavourable residual stresses in the material.
3. Both end plates are in contact with nearly a full turn of wire.
4. The end plate loads coincide with the spring axis.

Appendix 3

DESIGN METHODOLOGY
Basics of Material Selection (Ref Ashby Ch 5)

Material selection in design demands profile of material attributes. Ashby likens the process to that of hiring a new staff member.

1. Develop profile
2. Apply property limits
3. Develop material index by considering combination of attributes
4. Make choice

Deriving Property limits and Material Indices
The main considerations are:

1. Function: What it must do? -support load, insulate against cold.
2. Objective: To optimise performance -cheap and as strong as possible.
3. Constraint: It must achieve -cost < $100/kg, deflection < 1/500 span.

Component must achieve objectives whilst still meeting constraints.

Performance

Performance P dependant on

1. satisfying functional requirement F
2. the geometric parameters G
3. the material properties M

This can be stated as: $P = f[F, G, M]$
or: $P = f_1(F) f_2(G) f_3(M)$

Maximise performance by maximising $f_3(M)$
where M is known as the **Material Efficiency Coefficient** or **Material Index**

Case Study
For the whisker pole case study where minimum mass m is the required objective,

$$m = \left(\frac{4P_C}{n^2\pi}\right)^{1/2} \left(L^2\right) \left(\frac{\rho}{E^{1/2}}\right)$$

Given a specified length L, and load P_C, minimising mass requires maximising the material properties term. Our material index thus becomes

$$M = \left(\frac{E^{1/2}}{\rho}\right)$$

where E is the elastic modulus and ρ is the density. As can be seen from the following chart, materials are naturally grouped within contours, or envelopes of performance. Materials which lie along a particular $\left(\frac{E}{\rho}\right)^{1/2}$ gradient line perform equally well. Materials above the line perform better, those which fall below the line do worse.
Choosing a particular gradient provides a search area, which can be further narrowed by adding property limits.

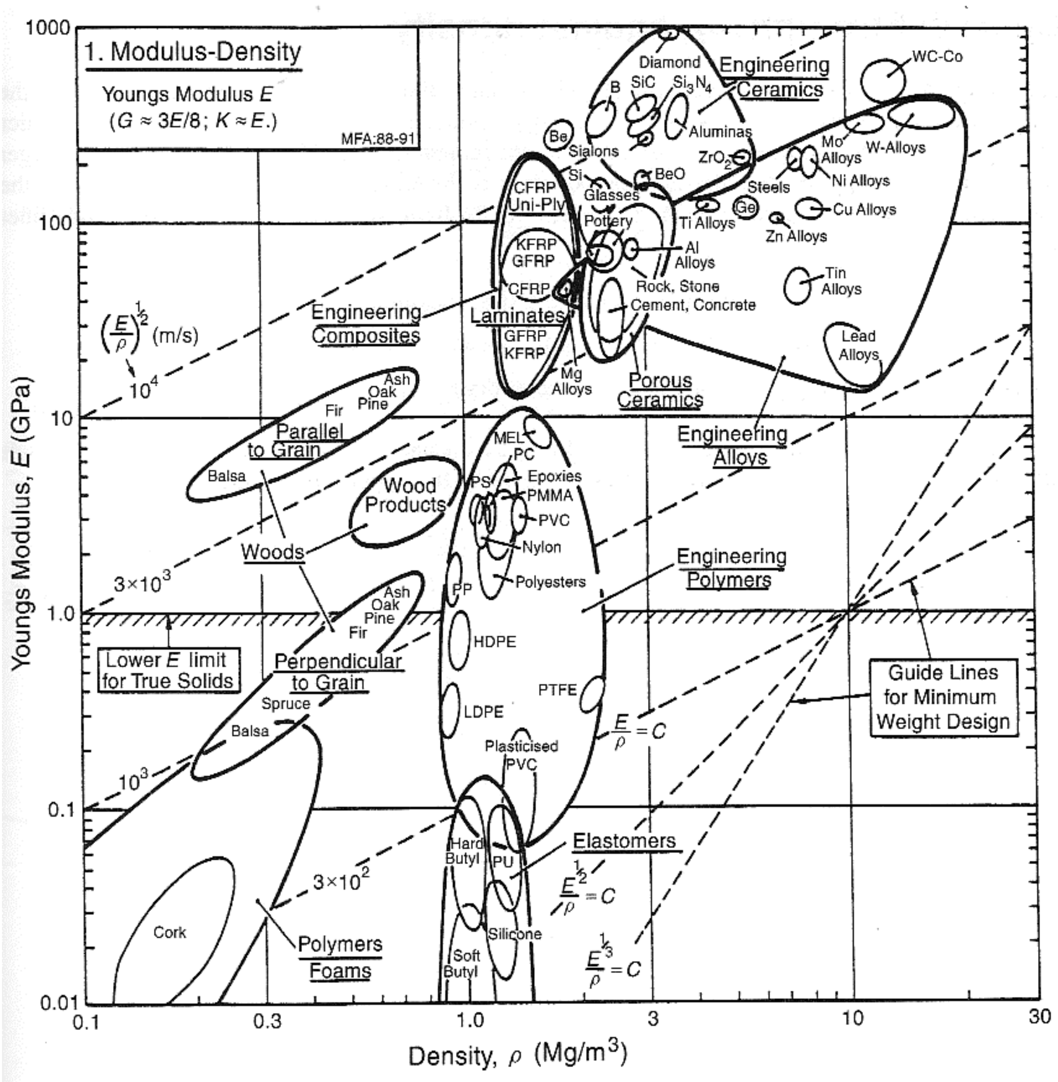


Chart 1: Design Methodology: Young' Modulus, E against density, *ρ* from Ashby, 1999, p419

Restructuring the lecture/tutorial model for effective learning

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Abstract: *In traditional engineering courses, lectures are delivered in hour blocks and tutorials follow up in other hour blocks with examples designed to illustrate the lectures. Often the tutorial is delivered by a different tutor to the lecturer. Student feedback on this type of teaching identified impediments to learning including poor class scheduling, inappropriate room type, and tutorial questions being too easy, hard or not relevant. Student feedback also indicated that a better model for tutorial teaching includes tutorials embedded in lectures. An example of a two hour lecture period with an embedded tutorial is given.*

Keywords: *active learning, tutorial, student feedback*

Introduction

A typical engineering undergraduate spends many hours in tutorials. Most engineering programs invest a significant amount of resources in tutorials, including academic staff time, tutor time, and room occupancy. It is a widely held belief by teaching staff (and students) that the student "needs" tutorials. This is supported by our own experience – most of us learnt engineering in this way. However, the attendance rates at tutorials for RMIT Chemical Engineering students have been observed to be as variable as attendance rates at lectures, suggesting that many students do not believe that tutorials are as beneficial to them as we like to think. A study was undertaken with 2nd year Chemical Engineering students to elucidate why this might be and how tutorials could be made more effective.

The traditional model for lectures/ tutorials

The role of the traditional tutorial is to give students the opportunity, in the presence of a tutor, to tackle questions related to theoretical concepts outlined in a previous lecture. While there is variation in the model between programs and universities, there tends to be some common patterns. Rules such as "one hour lecture/one hour tutorial" may be used to set up class schedules. "Suitable" rooms are allocated for each, such as sloping floor for lectures, so students have a good view of the front of the room, and flat floor for tutorials, so the tutor has close access to the students. A "large" class may be broken into "smaller" groups for tutorials, which must then be repeated for each group. This requires repeat performances by staff, which increases the burden on a limited resource. Furthermore, the size of the smaller group varies and tends to depend on staff workload rather than on what is a sensible size of group to teach.

This model was not designed to suit the learner and problems with it include:

- inflexibility due to scheduling and room type,
- discontinuity from lecture to tutorial because of change of venue/time,
- delays for some groups when multiple tutorials are scheduled,
- fatigue of staff teaching repeat classes, and
- the limited quality and quantity of one-on-one conversations possible in tutorial groups that are too large.

From a student's point of view, the traditional tutorial is often a poor quality learning experience.

Directions for restructuring

An unpublished paper by Hadgraft (2000) emphasised that good teaching requires a balanced approach across each subject. Hadgraft argued that focusing on only one aspect of teaching, whether it be the lecture, tutorial, or resources, will not yield satisfactory learning outcomes for students. Hadgraft presented "an overview of teaching practice" and identified that after a "wealth of material" has been made available to students in whatever way is appropriate, students must be able to engage with the material and have opportunities to link practice activities back to original concepts/ learning objectives. The size of the activity will lead to development of different outcomes. "Small" activities such as ten minute tutorial questions would lead to development of individual skill, while "large" ones such as an assignment completed over a number of weeks or a semester long project would lead to understanding of professional practice in a broader context. This clearly identifies the purpose of tutorials as a time when small activities should lead to development of individual skills.

Hadgraft (2000) also identified the importance of interaction to achieve student engagement. Inherent in the interactive exchange is the opportunity for the learner to receive valuable, immediate feedback (Peterson and Swing, 1985), which is when the learner is most receptive. Interaction fosters formulation and development of ideas (Johnson, 1971) and assists in the consolidation and strengthening of what is known (Johnson and Johnson, 1992). More educators are now recognising that interaction between peers is a particular useful learning strategy (Murray, 1999). The participants are more comfortable because the interaction is exchanged on a level that both participants understand (Damon, 1984). Whether with tutor or peer, in a participatory context, the student is in a position to learn, from one-on-one interaction, specifically what he or she needs, by requesting clarification or challenging the position taken and so on. This is when students feel most actively involved in their own learning. This also leads students towards self-evaluation their own level of understanding, which in turn leads to taking more responsibility for their learning.

What students think about different types of tutorials

How can we know what students consider an effective learning experience? Or what kind of environments and conditions support their learning? Collecting student feedback can be an onerous, time-consuming affair, and undertaking too many surveys can lead to feedback-fatigue. Crisp interactions leading to immediate visible changes are most desirable from a student point of view. In this instance, students in the second year of Chemical Engineering at RMIT (a cohort of 50 students) were surveyed, as a group, about tutorials. Tutorials generally cater for 20 to 30 students. Initially the group brainstormed answers to particular questions that aimed to identify the range of tutorial experiences familiar to the students. Then "popularity" of the various categories and conditions were determined by asking the whole group to vote by a show of hands.

The first question was: "what types of tutorials are there?" The students identified the following tutorial "types". The "popularity" of each is shown as the % of the class that voted for each category.

Tutorial Type	*Most popular*	*No opinion*	*Least popular*
Embedded in lectures	50%	25%	25%
Tutorials held in a flat floor room	50%	50%	0%
Tutorials held on a different day to the lecture	5%	80%	15%
Tutorials that work through set problems	25%	60%	15%
Tutorials that work through problems of your own choice	0%	75%	25%

Table 1: Popularity of different types of tutorials with 2nd year students

An attempt was made to elaborate on the popularity of the various types by asking the students what was good, or not good, about them.

"What's good about that tutorial type?" yielded the following responses:
- If the tutorial is straight after the lecture and in the same room, it's no effort to attend.
- You get to attempt set practice questions.
- It helps you to solve assignment questions.
- If the tutorial is in a flat floor room it's then possible to have a one-on-one discussion.
- You use the knowledge that you learned in lectures. They help to clarify the learning from lectures.
- If the tutorial is the same day it helps to use the knowledge straightaway, it's easier to remember.
- Having a post grad tutor is good – they explain it in language we understand.

"What's *not* good about that tutorial type?" yielded the following responses:
- If the tutorial is on another day or after a free period, it's too easy not to attend.
- If the tutorial is straight after the lecture, its too much if its more than 2 hours.
- If you work on a set problem that is the same as on the assignment, if you can do the assignment already, it's not worth attending.
- If set problems are given prior to the tutorial, it's frustrating if you can't solve them on your own.
- If there are no set problems, there is insufficient structure for you to get a benefit
- If there are set problems, don't spend a whole hour on one question!
- It the tutorial is at the end of a day, you are too tired to focus on the subject.
- If the tutorial is on another day, you forget a lot, there seems to be discontinuity.

The issues identified by the students fell into the following broad categories:

- motivation to attend tutorials
- development of skills during tutorials
- linking the tutorial experience with the lecture content.

Clearly these issues are also causally related. Lack of motivation to attend was exacerbated by poor class scheduling, room type not conducive to interactive contact, and being tired. Development of skills was hampered by questions being too easy or too hard, too unstructured or too drawn out. Poor class scheduling diminished effective linking of the tutorial experience with the lecture content.

On the other hand, motivation to attend was increased by good class scheduling, development of skills was augmented by engaging with relevant questions and getting one-on-one help, while linking learning to material from lectures was seen to increase with the 'doing' of examples ("using the knowledge"), good class scheduling and opportunities to access peer/postgraduate tutoring support.

The last question was: "what's the ideal tutorial?" Responses included:

- a mix of lecture and tutorial with max 30 minutes of lecture,
- having a choice of set questions to attempt,
- availability of postgraduate (other) tutors.

To return to Table 1, there was a significant minority of students [25%] who indicated that they disliked the "tutorial embedded in a lecture model". This view was at the opposite extreme to the majority of the class [50%] who preferred this model and to most of the views expressed during the discussion. It was unclear what type of tutorials this minority preferred. Due to time constraints and the dynamics of the group survey this was not fully explored during the survey session. Possible reasons for this difference include:

- some students have never had a good learning experience at a tutorial
- some students lack skills needed to recognise effective learning environments
- some students wish to avoid developing a relationship with their lecturers
- some students do not feel confident about discussing their work in a group

This remains an interesting point for further discussion with the students.

The ideal model for a tutorial as perceived by the 2nd year students was developed as a mindmap as shown in Figure 1.

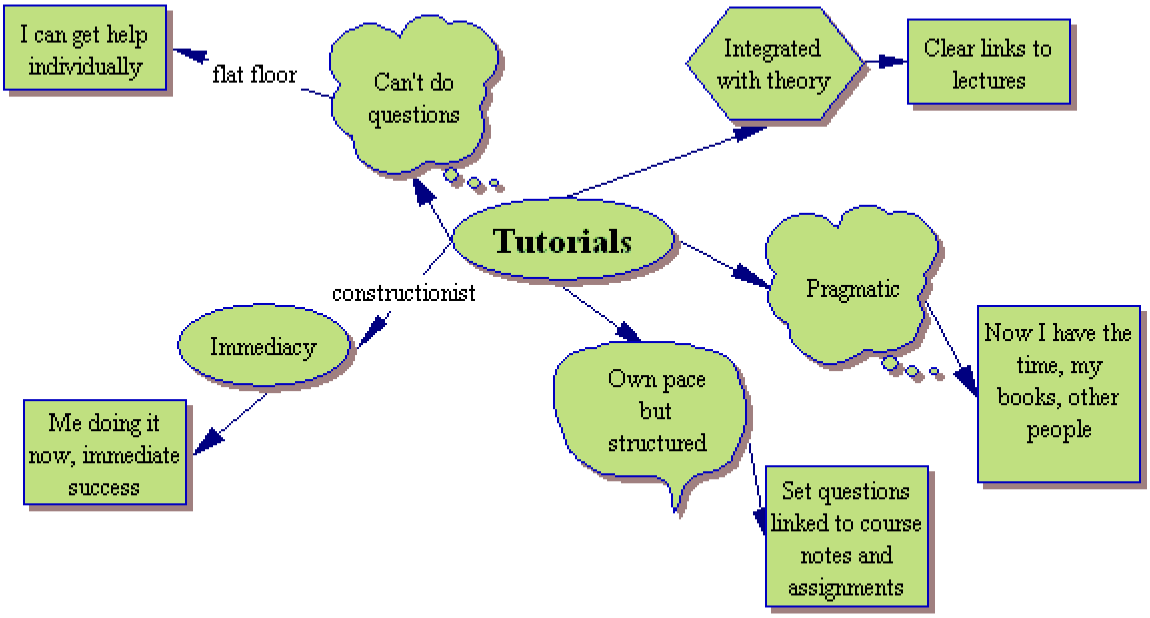

Figure 1: Mindmap of the ideal tutorial as perceived by 2nd year students

Discussion

The response to this group session suggests that these students were adopting a very pragmatic approach to their study experience. This is consistent with the findings of a study by McInnis et al (2000) that showed increasing numbers of full time students are employed in part-time work and that attendance at university is no longer perceived as a place where students go and stay for the whole day – every day of the week. Whatever the academic opinion, students are making judicious decisions on a day-to-day basis regarding their attendance at tutorials and lectures. The students' decision to attend/not attend and engage/not engage is based on expected value gain for the time/effort invested. An unpublished PhD thesis by Anderson documented at a later stage (Anderson, 1997) identified that an informal group atmosphere is important in fostering active participation and listening. That is, if students felt comfortable in asking questions, particularly in regard to difficulties in understanding the work, then more learning would take place. This correlates well with the popularity of postgraduate or peer tutors who are perceived to be more approachable than the lecturer because of their ability to explain things in a way that students understand.

The popularity of the "embedded tutorial model" (Table 1) suggests that some students are having good quality learning experiences in some tutorials. However, there was a sizeable minority who did not like this model. There was also no general consensus on what students would like to do at tutorials – work through set questions or problems of your own choice were only voted for by 25% of the students. This suggests that there are other options students would like, that were not identified in our survey.

So what else would they like?

Hadgraft's (2000) study suggests it is ineffective to tinker with tutorials without considering the course as a whole. Anderson (1997) suggests that comfort level in asking for help is the key issue, rather the content of the set questions/problems. Clearly this particular study has not addressed all the issues.

An alternative model for teaching tutorials

A number of students identified a good example of the 'best tutorial type' as that offered in a Mineral Processing class. This lecture/tutorial is outlined in more detail below.

A model class plan is illustrated in Figure 2, where each block represents 5 minutes of a total 2 hour class. This particular class is an introduction to the principles and technology of reducing the size of ore pieces during mineral processing.

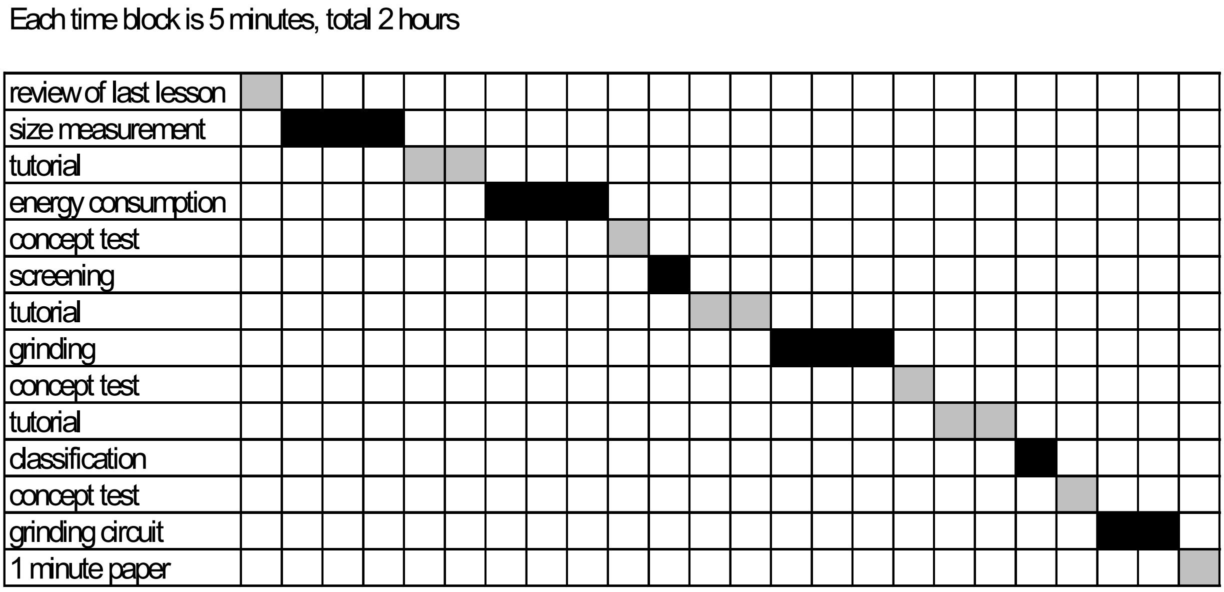

Figure 2: Structure of class on size reduction in mineral processing

There are six periods of "mini-lectures" which utilise Powerpoint presentations. This has the benefit of limiting how much can be written on each slide and enabling colour photographs of equipment in operation to be easily be shown. Each mini-lecture lasts no more than 15 minutes, and preferably less. The students are provided with printed copies of the slides to avoid the necessity of trying to write and listen simultaneously. The mini-lectures are not monologues but are studded with short questions eliciting student responses.

The tutorial sessions last for only about 10 minutes, but are extended if it seems necessary. Students work on simple calculations that emphasise and expand the previous mini-lecture. The calculations are especially designed to increase the familiarity of the students with industrial operations and with their scale. The lecturer, and tutor if available, walks amongst the students during the tutorial to check progress with the calculations and to both ask and answer individual questions on the mini-lecture content. Model answers are shown on the screen and discussed at the end of the short tutorial block. Students are told that after each major section of work (3-4 weeks) they will be given a hard copy of all tutorial answers.

"ConcepTests" (as developed by Mazur (1997)) are used to test whether a key concept is understood. They also serve to signal to the students which are the key concepts. They are conducted in the usual way in that students are first asked to think and answer a set question individually. Their answers are then checked by voting by a show of hands, or by hidden signals (fingers against the chest to show their choice of answer). If there are many wrong answers then the students are asked to discuss their answers with a classmate, followed by an second answer check. Finally the correct answer is given together with a brief explanation, and can be made more full if there still seems to be uncertainty. Often the ConcepTest questions are not in the context of the class, in this case size reduction, but are made more lateral to create interest and reinforce the idea that key concepts are of a more generic value. Finally, there is the occasional use of the 1-minute paper at the end of the class to see if students can link some of the key concepts and to provide feedback to the lecturer.

The perceived benefits to the students of using this embedded tutorial model for classes are;

- only relatively short periods of attention and concentration are required,
- they become impatient to relax and talk, and this is utilised for productive work,
- they can ask the lecturer questions about content in "real time" and don't have to wait until the end of the class or during the week,
- shy students are not deterred from asking for help because they can do so individually rather than publicly,
- signals are given as to what are the key concepts which need to be grappled with,
- signals are given as to what type of calculations are important, and at what level of detail or mathematical complexity.

There are also significant benefits to the lecturer that outweigh the increased level of preparation and thought required before the class;

- shorter lecture sections are less tiring and stressful to deliver,
- concept tests provide real-time feedback on the level of depth understanding,
- tutorial time is an opportunity to get to know the students,
- individual learning styles and needs can be assessed, as well as individual levels of understanding and motivation,

The lecturer found lecturing in this way particularly enjoyable thanks to the informality of the class and had a much more relaxed and confident experience. Quiet and attention was required during the mini-lectures, and it was generally found that the students respected this need of the lecturer when their need to relax and talk together was also recognised. The opportunity to get to know students personally was probably the most rewarding outcome, and as a result they showed little reluctance to come and talk frankly about their problems with the lecturer. Despite the informality, the lecturer actually felt far more in control of the class and student learning because of the high level of immediate feedback. This led to a great deal of personal satisfaction from the perceived achievement of a much deeper level of understanding by the students.

Conclusions

There is widespread dissatisfaction among students with their experiences in traditional tutorials. A class of second year chemical engineering students was asked to describe different types of tutorials and what was good or bad about them. Their feedback on those types reflected major issues of motivation to attend, development of skills at the tutorial and linking the tutorial experience with the lecture content. Motivation was increased by good timetabling, being asked relevant questions and getting one-on-one help. Linking the tutorial experience to the lecture content was enhanced by good timetabling, and peer/postgrad tutoring. Some students could not identify what they would like in a tutorial, and this remains an outstanding question. The most popular tutorial type was the "embedded in lectures" model. This model combines lecture and tutorial, limiting time spent on each to 10 to 15 minutes. Level of understanding is tested with ConcepTests and 1-minute tests. This model is popular with 2nd year students and the lecturer alike. More work is needed to establish a model that meets the needs of all students.

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Action research into project based learning in a computer design course

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Abstract: *This paper presents the experiences of the author and the outcomes from an action research project in an advanced course on computer design. The past experiences of the author indicated that students encountered enormous difficulties during the implementation stage of a practical design project in the course. The aim of the action research was to investigate how the students' learning experiences and outcomes could be improved. The strategies implemented centred around learning from the experiences of the peers and self-assessment. Class project meetings were used as the main forum for implementing and refining the strategies over a number of cycles. The criteria for evaluation of the strategies implemented were student evaluation, project outcomes and feedbacks from colleagues.*

Keywords: *Project-based learning, peer learning, reflective practice*

Introduction

Is everything about engineering purely applied science? Is engineering always a matter of following a predetermined set of rules, procedures and processes? Or is it as much an art as it is a science? Do engineers need qualities such as *critical thinking* and *reflection*? If they do then what are the best ways to develop them?

The *Employer Satisfaction with Graduate Skills* report, released in March 2000, noted that technical skills in most disciplines become obsolete within five years; so, employers need graduates with the ability to handle those changes. That particularly means *critical thinking* and *communications skills*. However, the survey noted that many Australian university graduates lack these qualities (Lloyd, 2000).

While teaching a final year engineering course on Computer Hardware Design at the University of South Australia in the year 2000, I observed that students were faced with difficulties in implementing a practical design often leading to a stage where they didn't have any clue as to where to go from there. The rigorous engineering methodologies, debugging techniques and testing strategies weren't proving to be adequate in many cases. Faced with this situation I decided in the year 2001 to embark on an *action research* (Kemmis and McTaggart, 1988) project to explore how the students' learning experiences could be enhanced. The primary encouragement for doing this came from my own study in a program in Graduate Certificate in Higher Education. This presented an opportunity for me to immediately apply some of the knowledge I had gained from the program to attempt solving a *teaching problem* in my own classroom.

Outline of the student project

The computer design project forms a significant part of a final year course whereby students are required to design, implement and test a single board computer in groups of three. In addition to acquiring a core body of knowledge and developing practical design skills, the project aims to assist students in preparing for a professional career as an engineer when they would be expected to be involved in similar projects of much higher complexity. However, I observed that the students faced many problems during the *practical implementation* of their designs leading to frustration in some cases. As an example of a typical problem, students would say that the computer they had assembled would not work (do nothing), and despite checking everything they could not identify the source of the problem. The problem could be the result of errors in the original hardware design or errors in the software, or simply a solder joint on the circuit board that had cracked.

From my observations the reasons for these problems are manifold. Building the computer involves complex wiring of many electronic components on a single circuit board. Identifying the source of potential problems in such a complex circuit board can be a very challenging and daunting task. In addition, various design issues are intentionally left open ended to allow students to exercise their understanding of the area and *problem solving* ability. This is aimed to provide students with adequate opportunities for training in dealing with open-ended design problems. However, this can also add to the complexity of the problems unless the students are able to reflect on the design choices they make, and ask themselves why they made certain choices, how could those be changed and for what possible outcomes, how their peers dealt with similar issues, and which approach was better. I felt the need to bridge an apparent gap between the technical activities involving design, implementation and testing, and the students' abilities to reflect on their actions, think critically, do self-assessment, learn from their peers' experience, and above all communicate effectively. It is hard to imagine engineering graduates succeeding in their professional career without these important qualities in an era of phenomenal technological and social transformation.

Reflection, planning and action research

One of the key features of *action research* as outlined by Kemmis and McTaggart (1988) is: "action research is an approach to improving education by changing it and learning from the consequences of changes". They stressed that action research is *collaborative*, thought it is important to realise that the action research of a group depends upon individual members *critically examining* their own actions (Kemmis, 1999). An action research would incorporate planning, introduction of new strategies, analysing the impacts of these strategies and changing the strategies based on *reflections* on the previous ones (Burns, 1997; Kemmis and Wilkinson, 1998). Action research has been seen to be synonymous with reflective practice (McMahon, 1999). Indeed, I see reflective practice very much as part and parcel of any action research that aims to bring about changes in the way we teach.

So, before planning any new activity or making changes to the existing ones while delivering the course in 2001, I began to *critically examine* the learning activities undertaken in the previous year. I reflected on the various activities and their outcomes, and also considered the student feedback and final project outcomes (successful completion of project). One of the activities undertaken in the year 2000 was a seminar held in the third week of the semester where all students presented their initial designs in front of the entire class. Although many students were initially very shy about making such presentations (especially those from non-English speaking backgrounds), almost all students said that they had benefited from the exercise. Listed below is a summary of the positive feedback provided by students:

- Participation in the seminar increased their confidence in making presentations.
- Peers pointed out errors in their design and they could fix those errors before proceeding with the implementation. That was really helpful.
- Many students could see how their peers did certain things differently (in a better way).
- Students could describe the problems they had faced in doing the design and seek solutions from their peers' presentations or by asking questions to their peers.

As the above feedback demonstrates, students received useful *feedback* from their peers. They could enhance their understanding of the design and enrich their learning through *self-assessment* and comparison with their peer's work (Nightingale and others, 1996).

There is much research that demonstrates interaction among students, both spontaneous and formal, facilitates students' learning and helps students achieve the learning goals (Johnson and Johnson, 1990; Topping, 1996). Yet in my role as *session chair* of the seminar I occasionally asked questions that were relevant and not asked by the students. It therefore appeared to me that the benefits of *student-student interaction* could be further exploited in order to assist students during the implementation stage of their projects. However, I also recognised that it was an unrealistic aim to expect productive student-student interaction without some facilitator input. Herein lies the challenge to find the appropriate balance on the continuum of *teacher-centred* and *student-centred* pedagogic approaches.

Strategies

In 2001, before planning some new activities to facilitate interactions among students during project implementation I had decided to address one issue arising out of the seminar in the previous year. Many students commented that they did put in a lot of effort in preparing the presentation and would have liked to be rewarded. Some even said that they did not put as much effort as they could have because there was no mark allocated for the presentation. This made sense to me considering that the students had completed a design for presentation in the seminar and it gave their project a kick-start early in the semester. Some of the presentations were very good in terms of contents and quality. So, I decided to allocate 5% marks for the seminar in 2001. I expected that this would increase student motivation (November, 1996) and also continue to provide students with useful feedback. I suggest that allocating some marks for the seminar makes it a *summative* as well as a *formative* (Biggs, 1999) assessment task, although many might argue.

On the more important question of how to facilitate *student-student interaction* and *peer learning* during the implementation stage of the project, the weekly practical sessions appeared to be the most appropriate place. There were two practical classes of two hours duration with approximately 18 students in each. I felt that allowing 15 minutes time at the beginning of each practical class would be appropriate. I called this activity *class project meeting*. Students worked in groups of three in the computer design and implementation project. The essence of the interactions in the project meetings was to encourage students from different groups to interact, exchange ideas and benefit from each other's experience. Students would be expected to talk about the problems they were facing in their project, hear from their peers whether they had similar problems and how they went about solving them. In addition, students would be expected to share experiences, which they thought might assist other groups of students. From the assessment point of view the project meetings were *purely formative*. After each meeting I analysed the impacts of the strategies by examining student participation and feedback. Based on my reflections I modified the strategies in the next cycle to increase the learning outcomes. In total I ran *six cycles* of project meetings in this action research for two different classes. It was based on Lewin's cyclic model (Lewin, 1946), and closely resembles other derivatives of this model, such as a spiral of cycles of reconnaissance, planning action, enacting and observing the planned action (Kemmis, 1999).

Implementation, evaluations and outcomes

The various strategies implemented for the project seminar and project meetings, and their outcomes are presented in this section. Also included are my reflections, student evaluations and feedback from colleagues.

Project seminar

As stated earlier, 5% mark was allocated for the seminar. Students were advised to complete their first designs and present in a seminar in the third week of the semester. The format was ten minutes of presentation time for each group followed by two minutes for questions and discussion. Each member of a group was required to take part. Most groups used overhead transparencies for the presentation while some groups used power point slides. In the previous year none of the groups made power point presentations. On average the quality of presentations was better than those of the previous year. It was perhaps due to the fact that the seminar carried some marks and the students were more motivated to work for something that would count toward their final grade. Some interesting questions were asked and discussions were generated from most presentations. Students pointed out errors in a few designs.

Evaluation of the project seminar

I prepared a survey questionnaire for student evaluation of the project seminar. Twenty-one students returned the questionnaire. Most of the students said that the seminar was very useful for getting feedback, for assessing their own as well as their peers' work, learning from other presentations and improving presentation skills. Twenty students said that the requirement to present the design in the seminar had an impact on the work they had done on the actual design. The majority (81%) of them had worked harder to complete the design before the seminar and had prepared for the presentation. Two third of the respondents said that they had put more effort to understand the design and that there should be more presentations in this course. Most (90%) of the respondents were in favour of having (at least one) presentation in other courses as well. However, 62% said that the *time allocated for the* *presentation and discussion was too little*. A colleague who was present in the seminar also expressed similar views and recommended that the time for presentation and discussion be increased.

Action research: class project meetings

In order to assist the students to assess their progress in the project I prepared a list of weekly *milestones*. The list was made available on the course web page at the beginning of the semester. The idea was to enable students to compare their actual weekly progress against these milestones as the semester progressed. I expected the students to use the class project meetings to assess their progress compared to the milestones, and then reflect and critically analyse their activities and outcomes if their progress wasn't up to the mark.

Cycles 1 and 2

The *first* class project meeting was held in week 5 of the semester. At the beginning I gave a brief overview on the objectives of the meeting and encouraged students to discuss issues of their interest and concern. The students raised only a few issues on their designs and administration of the project, but no project related problem was reported. I had to *intervene and mediate* in order to generate some discussion and explain how they could benefit by discussing issues related to the design and implementation of the project. It appeared to me that the students were unsure about their roles and were very passive. I used the *qualitative evaluation questionnaire* given in Table 1 to receive student feedback about the meeting.

- What are the three learnings you take away from this meeting?
- How did this session meet your expectations?
- How could it better meet your expectations?

Table 1: Qualitative evaluation questionnaire for cycles 1 and 2

Many students struggled to fill in the evaluation sheets and left parts of the questionnaire blank. I therefore found the student responses to be inadequate and superficial, and indicative of very little engagement in the learning task.

The *second* project meeting (cycle 2) was held in the following week with a different class. Considering the poor student participation in the first cycle, I *explained* the objectives of the meeting *in more detail* and *cited examples* on how they could benefit by discussing certain issues. I also stated what was expected of the students, how they could participate and contribute. Some of the things I pointed to were:

- Compare your progress with the milestones and *critically* analyse your observation.
- List the problems you faced. Did you attempt to solve them? How? Did it work?
- Report problems you successfully solved.
- Report on better (more efficient) ways in which you have implemented a certain thing compared to more cumbersome approaches you adopted earlier.

Student participation *improved slightly* compared to the first cycle. More issues were raised and discussed than in the first cycle. I used the same questionnaire (see Table 1) for evaluation by students. The responses were indicative of slightly better participation by the students than in the first cycle. It was perhaps a result of more elaborate explanation of the objectives and ways of engagements given to the students. However, in my judgement the level of participation was still not satisfactory. Many of the students said that they didn't have many issues to discuss at that stage as they had not completed building much of the hardware for the computer board and had not practically tested any module. Their primary concern at that stage was to get on with the assembly of the computer board. Despite limited student engagement the first two cycles achieved a student introduction to the idea of a class project meeting and its objectives. Although some students were unsure about how they could participate/contribute, many expressed the view that they expected to benefit from future meetings as the project progressed.

Cycles 3 and 4

In order to increase student participation I wanted to ensure that the students did put some thoughts into the activity and planned accordingly. I therefore wanted them to come up with an agenda for the meeting based on their experiences in the project. I handed out the *qualitative evaluation questionnaire* shown in Table 2 at least one week before the meeting. I advised the students to prepare the answers to the first three questions beforehand and bring these to the meeting. The idea was to encourage them to prepare for the meeting by doing *self-assessment* of their project, by engaging with the related issues, and by critically analysing them. This appeared to have worked quite well. Many students came up with various issues for discussion including problems they had faced in project implementation, various ways of implementing things, and how they had dealt with some of the problems they had faced. As a result I found the students much more *proactive* than in the previous cycles.

Part 1: Complete this section before the meeting

- How did you prepare for this meeting?
- Identify 3 questions related to your project that you want to have answered.
- How will you participate? What will you contribute? How will you get the answers to your questions?

Part 2: Complete this section at the end of the meeting

- What are the answers to your questions?
- What are the 3 most important things you learned today?
- What other questions were generated in today's meeting?

Table 2: Qualitative evaluation questionnaire for cycles 3 and 4

One important difference between the two project classes was that one class had the project meeting (cycle 3) two weeks before the other class (cycle 4). This was not something planned, the class schedule simply worked out that way due to holidays. Therefore the students of one class (cycle 4) had the opportunity to think about their projects for *two additional weeks* compared to the other class. I observed that the level at which the students of this class (cycle 4) carried out discussion was deeper than that of the other class (cycle 3). I had to do some *mediation* in cycle 3 while little in cycle 4. As students were getting more deeply involved with the implementation of the project and getting further insight into the task, they were more able to effectively participate, contribute and learn from deliberations in the meetings.

Students answered the second part of the questionnaire (see Table 2) at the end of the meetings. The responses indicated that the students gained much more than they had expected before the meetings. This was not only due to the planning, thinking and preparation before the meetings, but also due to their enthusiasm and willingness. It appears that the increased enthusiasm originated from their appreciation of the benefits of the project meetings.

Cycles 5 and 6

In these two cycles I decided to allow students to discuss their projects with very *little intervention and mediation* by me. Some groups had already got their computer boards working while others were still encountering problems. It was interesting to see that a few groups ran into difficulties with their boards after the boards had worked for a while. This was due to the complex nature of the computer boards containing many components wired together using more than a hundred wires. Despite all the problems the students took advantage of the project meetings to assess their works in the light of their peers' experience. They were spontaneously deliberating specific issues related to their projects in greater detail, critically reflecting on their actions and benefiting from their peers' experience.

Peer review of the project meetings

One of my colleagues was present in two project meetings. His comments about the activity were very positive. He especially recommended the use of the qualitative evaluation questionnaire given in Table 2 for such activity. Apart from this, I had philosophical discussions with colleagues active in the area of teaching and learning in higher education (Nafalski, McDermott and Gol, 2001) about the significance of project meetings and mediation. They agreed that mediation might be required during the early cycles of such meetings. However, they emphasised that as students develop better understanding and begin to see the relevance to their learning, they would be more motivated and able to take more responsibility in managing the proceedings of the meetings without much intervention from the teacher (McDermott, Gol and Nafalski, 2001). This is a view that I found to be in agreement with my experience during the final two cycles of the project meetings. I definitely observed the students taking more responsibility for their learning as they engaged in spontaneous discussion and analysis of project related issues.

With a view to gain feedback from a wider community of academics and researchers I presented the idea behind this work in a mini-conference in Adelaide organised as part of an Australian Universities Teaching Committee (AUTC) research project (Monash University, 2001). I was deeply encouraged by the very constructive feedback I had received.

Outcomes and observations

Ten out of twelve groups successfully completed and tested their computer boards. The percentage of successfully completed projects (83%) was higher than that in the previous year (75%). The most important outcome of the project meetings was the enhancement in students' learning experiences as indicated by the overall student satisfaction of the meetings. I used a *quantitative evaluation* questionnaire to receive overall feedback from the students. Twenty students returned the questionnaire. 79% of the respondents said that the meetings were useful because they could discuss issues related to the project. 80% thought that the feedback they had received from the meetings had helped them to judge their progress in the project. 90% said that the meetings were useful because they could see how other students dealt with some of the project related problems.

However, only 45% of the respondents felt that they had actively participated in the meetings. Interestingly 50% of the respondents were neutral on this question (unable to answer). These responses indicate that the students did not initially have a clear idea about the objectives of the meetings and were not sure about how they could participate/contribute. This is in agreement with my observations during the early cycles of the meetings. This illustrates the need for adequate and timely mediation by the teacher. As stated in Section 5.2.2 the use of the qualitative evaluation questionnaire of Table 2 assisted in increasing student participation in the later cycles. Perhaps an assessable student journal could be used to stimulate/encourage reflection thereby increasing participation and enhancing students' overall learning experience. As November (1996 and 1997) has experienced, a student journal has the potential to develop into a very useful tool for spontaneous reflection and for developing students' own experiential learning processes.

Conclusions

Class project meetings provided opportunities for enhancing students' learning experiences and outcomes through self/peer assessments and sharing of experiences. Timely intervention and mediation by the teacher were essential in order to maximise the benefits from these meetings, especially during the early cycles of the project meetings. Although many students were very passive during the early cycles, many participated more actively during the later cycles. Detail explanation of the objectives of the meetings, and on how students could prepare and participate was found to be very useful to encourage students. The qualitative evaluation questionnaire given in Table 2 was also found to be very useful to stimulate students' thoughts and to engage them in productive deliberations during the meetings. I would consider including an assessable student journal in future to enhance the positive learning outcomes from the project meetings and for a deeper learning experience.

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Acknowledgements

I would like to thank Dr Sally Clarke of Queensland University of Technology (QUT) for her constructive criticism and feedback during the course of this action research project in 2001. I would also like to thank Ms Fiona Underwood, Project Officer in the Information Technology Engineering and The Environment (ITEE) Division Office of the University of South Australia for proof reading this manuscript.

Alternative Assessments in Civil and Environmental Engineering

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***Abstract**: Examination greatly influences course structure and student study strategies. Three courses for students in the Civil and Environmental Engineering programs at Luleå University of Technology were reconstructed with the aims of making the assessment part of the learning process and to facilitate deep learning. Several different types of assessment were tested. Assessment in the form of a large project and field- and laboratory work was shown to be successful when applied to a course in snow engineering for university students with various backgrounds. A course in hydrology and hydraulics was reconstructed with the aim of assessing increasing levels of understanding. A simple written test was designed to assess lower levels of understanding (definitions, concepts etc.). Laboratory work, fieldwork and extensive assignments (calculation tasks) were intended to assess medium levels of understanding (apply, use and combine algorithms etc). A final oral group exam that was used to assess high levels of understanding (compare/contrast, explain causes, analyse, relate) concluded the course. A course in International Sanitary Engineering was assessed with cross-group presentations and literature seminars. Teaching and assessing features known to encourage deep learning approaches were adopted. Different types of peer assessment were tested with varying degree of success. For all three courses both the students and the teachers reported increased learning with these course structures and assessment strategies than from courses with a final written exams.*

***Keywords**: Assessment, learning strategies, peer assessment.*

Introduction

Assessment greatly influences course structure and student study strategies

That the type of assessment greatly influences both course structure and student study strategies have been shown by Bowden and Marton, (1998) and Marton et al. (1999). Surface learning strategies are characterized by: "Students focus their attention on the details and information in a lecture or text. They are trying to memorize these individual details in the form they appear in the lecture or text or to list the features of the situation" while deep learning is characterized by: "Students focus their attention on the overall meaning or message in a lecture, text or situation. They attempt to relate ideas together and construct their own meaning, possibly in relation to their own experience" (Biggs, 1999, Marton et al., 1999). Ramsden (1984) has shown how the learning environment influences student learning approaches. The same student may apply a surface or a deep learning approach depending on the learning environment. Course structures and assessment strategies that promote cooperative work in small groups with frequent and individual teacher response were shown to be important for study success according to Light (2001).

Most written exams at the end of a study period seem to favour student-learning strategies that lead to surface learning. One reason for this is that it is difficult to construct questions for a written exam that: a) students can answer in a few hours b) are easy to correct c) measure more than detail knowledge d) promotes learning during the exam itself. Another reason is that assessment solely by a written exam at the end of the study period encourages students to concentrate their study effort to a short period just prior to the exam.

Students at the Civil and Environmental engineering programs at Luleå University (LTU) claimed that written examination was a too dominating form of assessment at the university (Petterson and Jonsson, 1998). Since each assessment method will place some students at a disadvantage to a certain extent, a range of assessment strategies should be adopted to allow students who are at a disadvantage under one assessment method to excel in others (Brown et al. 1994; Gibbs and Habeshaw, 1998).

In order to increase the diversity in assessment forms and to facilitate deep learning, a three-year project “Environmental education with alternative assessment methods” was undertaken. The intent was to use a diversity of assessment forms to assess the theoretical knowledge of the students as well as their ability to co-operate, to analyse, to synthesize and to be creative. Methods to measure the depth of learning have been presented by Angelo and Cross (1993) but are beyond the scope of this study. Instead we tried to use factors which encourage students to adopt deep learning approaches when we reconstructed the courses (Bowden and Marton, 1998; Biggs, 1999) and tried to avoid those factors which encourage surface approaches.

The work with three of the courses: “International Sanitary Engineering” “Hydrology and Hydraulics“ and “Snow Engineering” is summarised here. The project lasted for three years so we had different numbers of students in the courses in the different years.

Reconstructed and new courses

The first two courses described below were originally rather traditional courses with lectures, exercises and a written exam at the end of the course, while the last course was already designed for assessment with a large project work component. All three courses corresponded to 4 weeks full work (6 ECTS credits) distributed over a period of approximately 10 weeks

Hydrology and Hydraulics

A mandatory course in hydrology and hydraulics was reconstructed with the aim of assessing increasing levels of understanding. The work with this course will be described in detail in Lundberg (2003). The goal for the course was to help the students to attain basic understanding of hydrological and hydraulic engineering processes. Between 45 and 90 students attended the course each year. We reduced the original number of lectures and exercises and after the reconstruction the course started with an introduction that explained the practical details and then a few “traditional” lectures and exercises followed. The rest of the course consisted of a short written test, laboratory work and a field task, and two large assignments concluded by a final group exam.

The SOLO taxonomy (Biggs & Collins 1982) stands for Structure of the Observed Learning Outcome and provides a systematic way of describing how a learner's performance grows in complexity when mastering different academic tasks. This taxonomy was used when designing the different parts of the assessment.

A simple written test was designed to assess lower levels of understanding (definitions, concepts etc.). Laboratory work, fieldwork and extensive assignments (calculation tasks) were intended to assess medium levels of understanding (apply, use and combine algorithms etc). The assignments were designed to imitate real engineering tasks. An example of a hydrology assignment was to estimate the risk for flooding due to the combination of large flow and ice jam. Students were assigned individual data for their assignments but they were encouraged to work together. They were also instructed to make the solutions clear and easy to follow. When they had completed their assignment, they handed over their solution to another student for comments. Not until their assignment had been corrected following the comments of their peer, were they allowed to hand in the solutions to the teacher. The same procedure was applied to the laboratory work report. A final oral group exam was used to assess high levels of understanding (compare/contrast, explain causes, analyse, relate) and this assessment concluded the course.

International Sanitary Engineering

The course "International Sanitary Engineering" was chosen for a test with assessment by literature seminars and by a large construction task with cross-group presentation. The course is offered as an optional course at Luleå University of Technology, Sweden, for students at the 4th or 5th year of the Environmental Engineering program and for exchange students from other universities studying similar programs. Water supply and wastewater treatment was dealt within an international perspective with focus on Asia, Africa and South America. The number of students varied between 10 and 25. After the reconstruction the course consisted of a few lectures, seminars, a term paper and a large construction task with cross presentations. The most interesting results dealt with the construction task, the cross presentations and the seminars and only those items are treated here.

Construction tasks with cross-group presentations

Cross-group assessment is described by among others Bessman et al. (1985). The aim with the assessment is that the students will be well acquainted with the subject when they <u>leave</u> the assessment occasion, not as for a written examination when they <u>arrive</u> to the exam. The students work with a rather complicated task (in this case a construction task) in teams of approximately 4 students per team. Let's assume there are 16 students in the course, the team members are then divided into four teams. Each team then works with the task for several weeks and suggests a solution to the task. One construction task given in this course was to design technical solutions for water supply and sanitation and suggest institutional arrangements for project implementation for a village in Africa. The tasks were based on real cases and the students were required to suggest solutions based on knowledge received during lectures, seminars and from literature found in a special library. They had to agree on the solution and each student needed to be able to explain why the solution was chosen. New groups (cross groups) were then formed with one member from each of the previous teams. In the cross-groups the members were supposed to report on and defend the solution suggested by their original team and then agree on a new final solution in the cross-group.

Seminars

Three seminars (45 minutes), which principally aimed at preparing the students for guest lecturers coming the following lecture, were given. Another purpose with the seminars was to give students a chance to discuss subjects not focused on technique but still relevant for the subject water and sanitation. Subjects discussed at the seminars were: a) Gender Aspects on Water Supply and Sanitation b) Planning, Implementation and Institutions and c) Hygiene, Water and Sanitation. The general arrangement of the seminars were similar even if the details varied. Before a seminar, the students read a collection of research papers and articles from books (20-50 pages) in groups of 2-3 students. They investigated the studied material together and prepared a presentation according to directions given by the teacher. After each of the different seminar presentations, the students were divided into groups of about 4 where they discussed questions delivered by the guest lecturer.

Snow Engineering

One course was assessed by a large team project where each team was assigned a tutor/ examiner. The work with this course is described in detail in Lundberg et al. (2003). The course chosen for this was a course in snow engineering for students with very varying backgrounds. The aim of the course was to give the students basic understanding of snow engineering processes and to improve general academic skills not directly linked to the snow-engineering subject. Examples of such skills are: oral presentation skills, report writing skills and co-operation skills. The course was an optional choice for students from the Master of Science in Engineering and University Diploma in engineering programs. Approximately 30 students ranging from their second to their final year attended the course. Roughly half of the students were exchange students from countries other than Sweden. The variety in student background meant that the student group was very diversified. The teachers represented three different Engineering disciplines so the diversity in teacher background was also larger than in most engineering courses.

The course started with an introduction that explained the practical details of the course and optional project suggestions. Then a few “traditional” lectures with basic knowledge about the snow subject were presented. The rest of the course consisted of three days of fieldwork followed by some laboratory work and a large project task. An ideal project task contains a literature review, a small practical experiment and consumer interest in the result of the work. Examples of projects used in this course were: “Pullout test of reinforcement in snow”, “Compare two different methods for evaluation of snow strength”, “Snow deposits, local or central?” “Snow removal as a resource”, “Use of remote sensing techniques to determine snow water equivalent”.

The students were to present the projects were in three different ways: a) as a short written report (≈5 pages), b) by a short oral presentation and finally in a third c) optional way. We provided the students with electronic links to snow- and cold-climate-databases, to electronic lexicons and to instructions for report writing, as well as instructions for poster and home page presentations.

The report was required to refer to a minimum of five articles (not textbooks) with correct references to those. We practiced peer assessment with the aim of enhancing the writing skills of the students. (A feedback evaluation sheet to check report structure, grammar/spelling etc was provided). The examiners graded the final report.

At the end of the course, student presentations were scheduled. Each group gave a short oral presentation (≈10 minutes) and presented their work as a poster, a home page, a physical model or in some other form. During the presentations, both the examiners and the peer (opposing) group assessed the presentation (evaluation sheet). Presentation structure, language, illustrations and performance were assessed.

The project was graded (report, oral presentation and optional presentation) by the examiners and peer assessment of individual team members' contribution was applied.

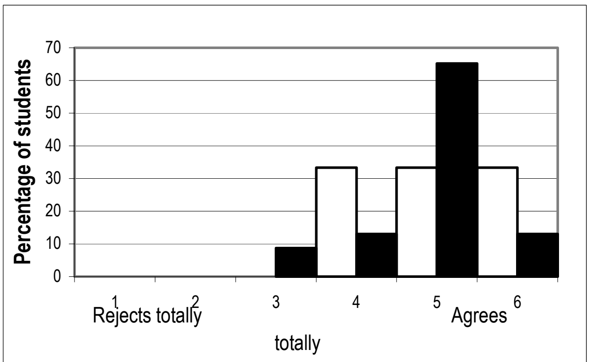
Evaluation of the courses

Slightly different types of evaluations have been made over the years depending on the type of course. The questions at the evaluation during the last study year (2001/2002) for the two courses Snow Engineering (SE) and Hydrology and Hydraulics (HH) were similar and are shortly reported here.

Student evaluation

At the end of the course, the students filled in a questionnaire about the course. They graded how well they agreed with a number of statements regarding the course using a 6-point scale. A score of six meant that the student totally agreed with the statement and a score of one meant that the student totally disagreed. Marks 4-6 on the 6-point scale were interpreted as positive to the statement.

The students seem to have appreciated the entire courses since 91% of the SE-course students agreed to the statement: *"The entire course has worked well"* and so did all the HH-students (Figure 1, below). The students also experienced that they had learned more with these types of assessment than with a traditional written exam at the end of the course since 96% of the SE-course students agreed to the statement: "*I have learned more with this assessment than with a "traditional" course with written exam at the end of the course"* and so did 93% of the HH-students: (Figure 1 below).



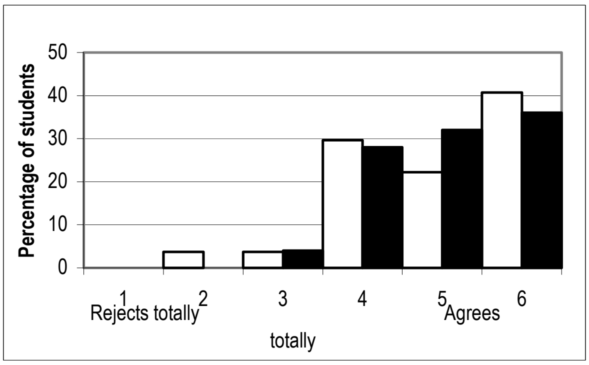


Figure 1: Percentage of students that agree with statements: Left: The entire course has worked well. Right: I have learned more with this assessment than with a "traditional" course with written exam at the end of the course. (SE course black and HH course white piles).

Teacher evaluation

The teacher evaluation consisted of informal discussions with the teachers. The teachers were convinced that the students learned better with this approach, but for the course in hydrology and hydraulics they still all expressed concern for a supposed decrease in width of student knowledge. The teacher workload was estimated to be approximately the same with the traditional written exam and more students passed the course.

Discussion

One of the aims with using these assessment forms was to promote deep learning. The students experienced that they had learned more with this assessment, but we did not really prove this. It is, however, likely that deep learning had taken place since we tried to avoid course characteristics (Gibbs 1997; Biggs 1999) associated with a surface approach and instead used features that can foster a deep approach. As an example factors are listed which can foster a deep approach with comments on how we succeeded in using them for the two courses Snow Engineering (SE) and Hydrology and Hydraulics (HH):

- Motivational context
  - the calculation tasks used in the HH course were constructed so they resembled real life engineering problems and this created a motivational context
  - most of the projects used in the SE course had a consumer interest in the result of the work; this created a motivational context.
- Learner activity
  - the calculation tasks used in the HH course as well as the the project work used in the SE course both required a lot of learner activity.
- Interaction with others
  - the students in the course HH were encouraged to interact with each other both when writing the laboratory reports and doing the calculation tasks. The oral exam was also based on interaction between students and with the teacher.
- A well-structured knowledge base
  - the initial traditional lectures and exercises used in both courses provided the students with a structured knowledge base.

Conclusions

General

Both teachers and students experienced that the students had learned more with these course structures and types of assessment than with courses with more lectures and a final written exam.

- It is likely that most students adopted a deep learning approach to the courses since we succeeded rather well in applying course characteristics that can foster a deep learning approach and in avoiding characteristics that can foster a surface approach.
- The workloads for the teachers were approximately the same with these course structures and assessment types as for courses with more lectures and a final written exam.
- It was very helpful to use factors which encourage students to adopt deep learning approaches and to try to avoid features that encourage surface strategies when we reconstructed the courses and the assessment.

Hydrology and Hydraulics

- The teachers experienced a deep learning approach among the students and more students passed the course but still all teachers expressed concern for a supposed decreased in width of the student knowledge.

- The major advantage with this course structure was according to the teachers the large amount of feedback the students got on their different assignments.
- It was difficult to convince the students of the benefits with peer assessment since they found the system too time consuming.
- The SOLO-taxonomy was helpful when designing the assessment types with the aim to assess increasing depths in understanding

International Sanitary Engineering

- The cross-group presentation used in this course to assess the project-work was successful since the students were very active and seemed to learn much during them. One difficulty however was that the teams who had first agreed on a rather poor solution had difficulties abandoning this solution when confronted with better solutions.
- Appreciated forms of literature seminar were seminars that involved all students such as: a) short role play/dialogues b) one team acted as seminar leader for the seminar.
- Discussions and open type problems where no obvious correct answers were given worked best for the seminars.
- When introducing literature seminars with the purpose to prepare students for guest lectures it is important to enhance the level of the following lectures.

Snow Engineering

- The resulting projects were generally of high quality.
- The students appreciated peer evaluation of the relative contributions to the project work.
- Two weaknesses with the course were identified: The teams were too large (4-6 student) and the course was too concentrated in time.

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Acknowledgements

This work was financed by the Swedish Council for the Renewal of Higher Education as the project: "Environmental education with alternative assessment methods" with project no 052/98. The teachers (Associate Professor Maria Viklander, PhD Signhild Gehlin, Professor Anders Sellgren and Senior Lecturer Lars Vikström) and PhD students (Annelie Hedström and Kjell Skogsberg) who taught parts of courses are acknowledged for their willingness to adopt these new assessment methods and for constructive suggestions to improve both course structures and assessment forms. The students Tina Roos and Sofia Hansson are acknowledged for their constructive criticism of new-constructed assignments.

Teaching Science "Spiders in Space Experiment" on Columbia STS-107

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Abstract: *The tragic loss of Columbia and her crew on 1st February 2003 stunned the world as debris was scattered over the Southern United States. This event was in stark contrast to the well wishers and clear blue sky that engulfed Space Shuttle Columbia STS107 as she took off on the 16th of January with eight Australian spiders on a sixteen-day mission into space. Students of the Glen Waverley Secondary College with RMIT University and the Royal Melbourne Zoo designed the experiment[10]. This process has led the students into direct contact and collaboration with established space entities NASA, Bioserve and Spacehab as well as international researchers. The class activities include the design of the experiment and investigations into issues such as life-support, flight clearance and mission simulation.*

The hypothesis tested whether spiders can build orb-webs in Microgravity conditions, and how Microgravity affects the web structure, method of production and quality of silk.

Despite the tragic loss of Columbia and her crew during the STS107 mission, the STARS experiment has yielded some insight that has assisted biological researchers in investigating the effect of micro gravity on the health and behaviour of spiders for the development of space a "Greenhouse". The development of habitat and automated feeding for spiders and similar life forms also provide valuable experience and insights into supporting life in space. The project demonstrates that being part of real-life space science and exploration is now a possibility for all young Australians.

Keywords: *education, science, innovation*

Introduction

Examination by NASA of early shuttle missions flown found that there was often excess payload capacity either in mass or volume. NASA realised that many small experiments could be accommodated within the orbiter's spacious payload bay, offering opportunities for schools to fly experiments. NASA initiative enabled a number of schools in the U.S.A. to play an active role in space research.

In 1998 SpaceHab Inc (USA) offered commercial learning package internationally for school experiments on the Space Shuttle. The program known as Space Technology and Research Students or S*T*A*R*S. The second S*T*A*R*S experiment was flown on STS-107, in January 2003 the participating schools[10] included the United States, Australia, Canada, Japan, China, and Israel[5]. This program was made possible by NASA's development of small payload containers to conduct a variety of space experiments[7], these experiments have a typical launch mass of less than one kilogram. Engineers and scientists from Bioserve at Colorado University, develop support hardware for the S*T*A*R*S experiments under contract to Spacehab Inc. Each experiment is assigned a container of specified dimensions and a place within the payload locker Figure 1.

Figure 1: The payload locker showing the spider experiment habitat, Assoc Prof Lachlan Thompson demonstrates how the astronauts took web samples during the mission

Each class, supported and mentored by a scientist(s) was responsible for experimental development and liaison with the launch provider. The class working with Spacehab to fulfil mission flight clearance requirements. The class was then provided with access to live and recorded mission data and a supporting curriculum from Spacehab.

Spiders in Space

The Australian S*T*A*R*S experiment on STS107, "The effect of microgravity on spider behaviour' was proposed by RMIT University[2] in response to a State Government Competition to find both an experiment and a class to participate in the Spacehab Science, Technology and Research Student (S*T*A*R*S) program.

The experiment being designed to be compatible with the Curriculum Standards Framework[1] (CSF-II) for years 7-12. The teacher selected to host the first Australian school space experiment was Ms. Caroline Need and her year 9 science students from Glen Waverley Secondary College in Victoria.

Figure 2: Glen Waverley Secondary College student Greg Carstairs from prepares the spidernauts food (fruit flies) at the Astrotech Facility Florida, preparing the experiment.

The GWSC class together with their teacher and researchers from RMIT University[10] and the Melbourne Zoo formed the core research team, or "Nova" class as used in the S*T*A*R*S program. The class of twenty-six students from year 9 is assigned into specialist research groups dealing with experimental design, spider husbandry, communication and collaboration with external researchers. Students are given specific research tasks for which their team has ownership and responsibility.

Students were required to interact with Spacehab in the USA through the protocols of experiment approval, hardware definition, live materials list, experimental protocol, "delta phase three" clearance (flight approval), and mission simulation. The experiment was originally to fly in December 2000, but due to a number of delays with modifications to the Columbia Orbiter Flight Vehicle the STS107 mission did not fly until three years later, with the launch on 16th January 2003. The long project delays meant that the student program had to be extended to keep the class involved in the experiment. The role the RMIT University in maintaining the program through this longer period was essential to the completion of the project. On completion of all milestones the experiment was to be shipped to Mission preparation centre at the Kennedy Space Centre.

Figure 3: Columbia taking aloft the dreams of discovery of the Glen Waverley students.

The STS107 Experiment

The STS107 Columbia Figure 3, spider experiment examines the effect of microgravity on the behaviour of spiders and the properties of their webs. This topic was chosen for its accessibility and appeal to students across a broad range of ages and capabilities. The experiment aims to add to the current body of knowledge concerning the biological effects of microgravity on living organisms with particular focus on web-building and the microstructure of spider silk spun in microgravity. Some insight into the suitability of spiders as pest control agents in a micro gravity greenhouse is also being investigated with the long-term application to a human mission to Mars.

Gravity is believed to have a strong influence on spider behaviour, particularly the way they move and build their webs. Gravity is thought to influence the thickness of their silk, the 'North-South' asymmetry of their webs and assist them to orient themselves, particularly in rebuilding webs that have been disturbed during the web-building process.

Figure 4; Left Australian spidernaut 'Slayer' training for the mission.

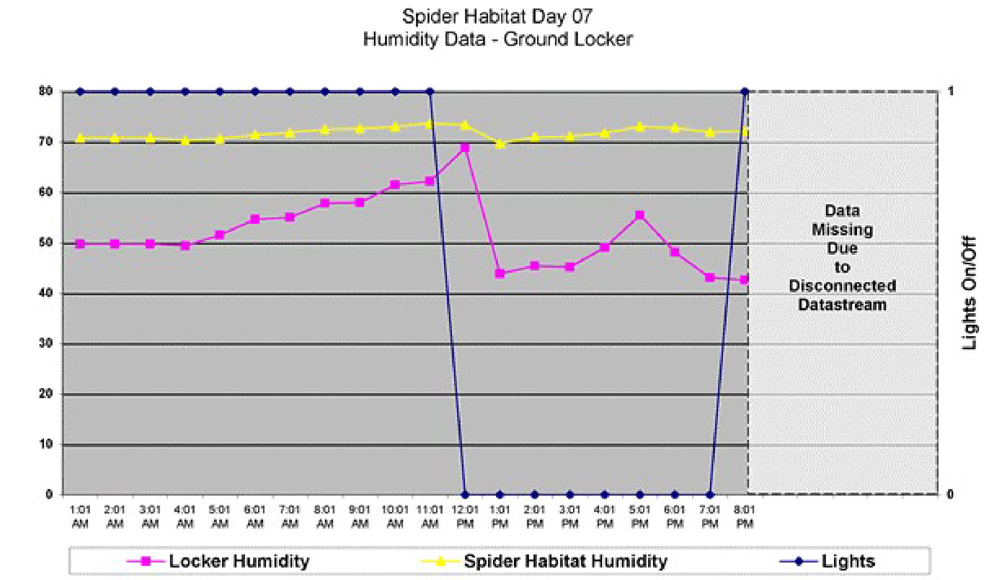
The spiders were monitored during day and night with still and video camera. The night photography was the most useful as the spider is nocturnal. Excellent images of the spider during its web making were taken. This allowed the class to examine the spider's web making prowess. While eight spiders flew on Columbia a second spidernauts team were undergoing the control experiment in an identical locker box and habitat.

Figure 5: Israel's first astronaut, mission specialist Ilan Ramon prepares to take a web sample on day 8 of Columbia's mission. (Photograph courtesy NASA)

To identify the spiders between the two groups they were each given a unique name. The lead spidernauts on the Columbia flight was "Wako" which is an Australian Aboriginal name for spider. The lead spidernauts on the ground-based control was "Cadbury". Observation of the Spider Habitat included video and measurement of Temperature, Day or night cycle phase and humidity, Figure 6. The charts shown below are taken from Day seven of the mission. The temperature in degrees Celsius varied through out the mission from 24 degrees C to 26.5 degrees C with an average Humidity of 60%. A humidity of 60% is a wet or moist atmosphere well suited to invertebrates (spiders and flies).

One of the operation problems with the experiment was that the spider is nocturnal. The other experiment in the isothermal module is daylight. In shuttle operations flights work on an 18 hour day with 12 hours daylight and six of night. This had the effect of reducing the quantity of useful data available to the researchers.

In both habitats the spidernauts were to be fed by the hatching of fly pupa laid in agar gel at the base of the spider habitat. Observations by mission specialist Ilan Ramon[11] confirmed that the biological feeder was working correctly. Analysis by the students of the downloaded experiment photography is being carried out to determine spider feeding activity. Analysis of the spider web pattern shows that the microgravity spidernaut made a more circular web than its earth bound control spider.



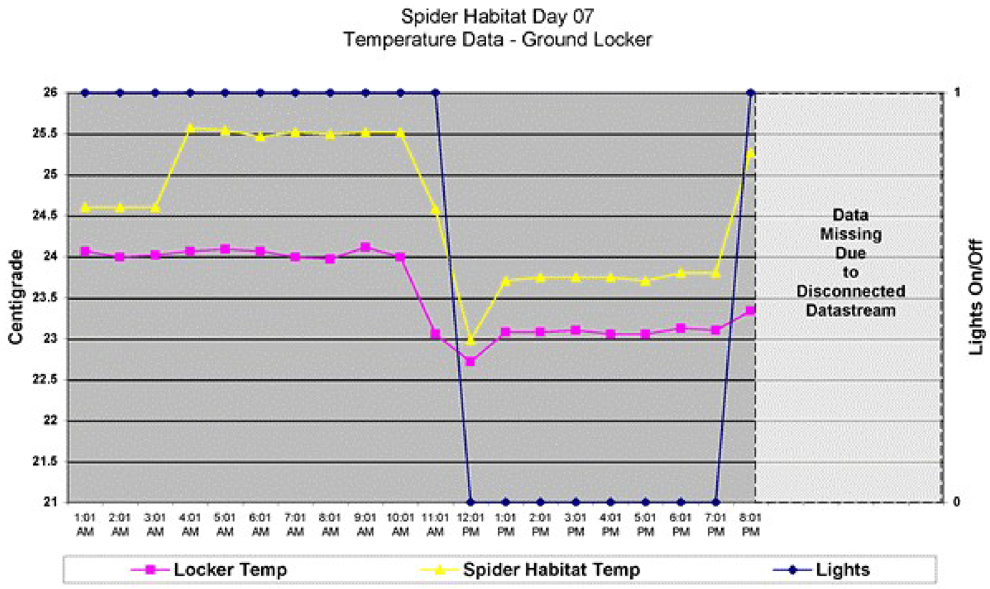


Figure 6: Humidity and Temperature Data charts were used by students to monitor the spider environment. Note the data stream failure.

Comparing the performance of the two lead spiders showed that "Wako" in Microgravity was able to construct her web in just over half the time of its land-based control "Cadbury". The video available of "Wako" show the spider deftly manoeuvring on the web compared to the earth bound "Cadbury". Other differences in web shape were observed supporting observations made by "Skylab 3". Analysis of the results has been hampered by the tragic loss of Columbia and her crew.

Research Outcomes

The science of the experiment has application to space life sciences where in order to conduct interplanetary human space colonisation bioenvironmental controls will be required to ensure a sustainable environment for the crew. Investigation and development of life support systems for spiders and similar life forms in space could contribute to knowledge necessary for supporting ecosystems in space.

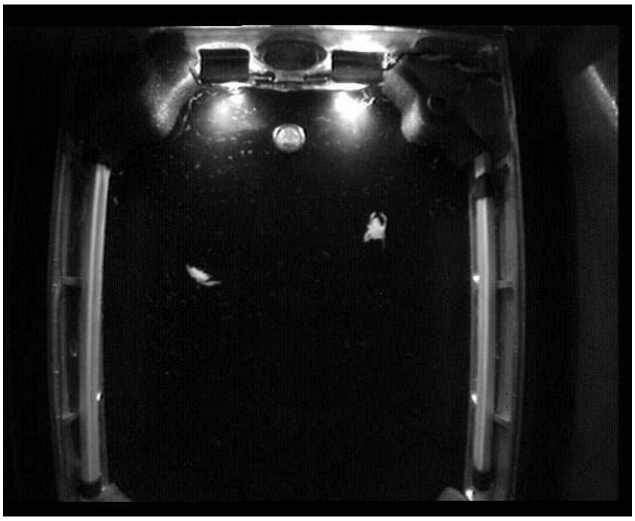


Figure 7: Poised in micro gravity aboard STS107 Columbia Aussie Spidernauts Wako (right) and Jenny (left) weave orb webs.

Observing how the spiders learn to move without the aid of gravity and develop new techniques for web building could possibly yield insights into techniques for building structures in microgravity. For example the two-dimensional nature of the spider-web is comparable to the large planar structures used to support solar and other arrays. Greater understanding of the construction and dynamics of these inherent 2D structures will facilitate the design and development of vast arrays to support future orbital space habitats and robotic devices required to construct them.

Educational Benefits

The students selected for the Spider project were taken from year 8 based on a typical grade distribution for that year of students. Twenty Six students joined the program on the basis that the S*T*A*R*S class was an additional load above normal year nine class work. In developing their hypothesis and designing their experiment the students of the NOVA class have gained insight into the role of science in our community. The students worked with telemetry data in a professional technical environment and budgets. The students conducted independent research activities and developed problem-solving skills to real-life situations. Some of the concepts that the students encountered during the course of the project include:

- The relationship between weight perception and web structure and microstructure.
- The role of gravity in orientation and web building/rebuilding.
- Adaptation to and movement in microgravity conditions.
- The phenomenon of fluid shift and other aspects of health in space.
- Spider biology and behaviour.
- Experimental techniques, and validation.
- The use of Clinorotation to simulate weightlessness.
- Running an experiment with minimal human intervention and contingency planning.
- Building a mini-space ecosystem, the development of a biological feeder.
- Life support needs to be met in a space environment.

- Shuttle missions: procedures, deadlines, and simulations, live materials list awareness of factors influencing shuttle launches.
- Objective analysis of experimental results.
- Working with professional scientists, astronauts and technicians to solve complex problems of science.
- To communicate the results of experiments to the professional scientific community.
- That science is an adventure and challenge at the frontiers of human achievement that drives individuals and teams, the pursuit of which is not without risk.

The 26 students worked with the project for two and half years leading up to the start of the VCE year when the team size dropped to 18 students for 2003. Comparing the student grade results to their comparative class and year groups the individual students in the program all achieved higher results than the expected. A detailed study is underway to quantify the academic performance of each individual student compared to their respective peers. This study will it is intended provide a quantitative measure of the educational experience.

Acknowledgements

The authors wish to thank the crew of Columbia who through their interest in the students and the experiment inspired the class to strive harder and fly higher.

The authors sincerely thank the Vice-Chancellor of RMIT University, Professor Ruth Dunkin, for her support and patronage of this project.

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Robot Competitions in the Curriculum

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***Abstract**: Robot competitions are growing in popularity as elements of both school and University curriculum This paper describes the development of a simulator and course for team robotics. Challenges of balancing workload and challenges are discussed in the context of further development of this approach.*

***Keywords**: autonomous robots, competition, simulators*

Introduction

The spectacular growth of robot competitions (robots.net 2003) since 1995 is at one level simply a phenomenon of growth of robot culture, especially in Japan. The dramatic drop in cost of the electronics for constructing robots has brought them within the reach of every high school enthusiast. The technology itself has matured dramatically: we can think of the size and cost of simple digital camera that is useful for robot vision. Although many companies were slow to realise the potential of robotics in educational settings, Lego were active pioneers in this direction, and the release of Lego Mindstorms (Lego 2003) propelled robotics into the higher school curriculum. Other companies (eg. Parker 2002) have followed with further development of the technology. In Australia, this has been evidenced in the spectacular growth of Robocup Junior with a presence in a very large number of high schools throughout the country. Verner (1999) describes the Israeli experience in detail: competitions act as a catalyst to attract students to systems approach to technology. He reports a very strong favourable response by students, with an indication that the competition is very influential in attracting them to technology courses.

But of course it is not just the availability of the technology that has fed the growth. In format they are closer to a sporting competition than a technology fair, making them very accessible to the general public. This is especially valuable in engineering, where although exciting to its followers, it is difficult to convey the joys of engineering to a broad audience.

As a participant in the robocup (Robocup 2003) robot soccer competitions, I would often say that "soccer is a more universal language than English". This is certainly the case: it is hard to find a corner of the world where soccer is not understood. The competitions are highly accessible, and serve as a first point of inspiration for many future technologists and engineers. Robocup has a number of leagues where teams of robots compete in a setting that is inspired by the human game of soccer. This provides for an event with a public audience, with intense competition between teams of technologists.

Researchers often have difficulty with the sporting aspects: a game is certainly not a scientific experiment. The real value of competitions here is that it serves to benchmark one against another in a standardised setting. Many approaches to robotics look promising in experiments but fail in the standard setting of a robot soccer game.

When we created the robocup concept, we took it as a natural successor to the "computer chess" competitions, which eventually resulted in the victory of a computer chess program over the world human champion. The computer chess challenges served to challenge our imagination of what is possible with a computer. Regardless of the merits of computer chess intelligence, it serves as an amazing landmark in the development of computer technology. The long journey from the public ridicule of chess playing computers in the 1970's and 1980's stands as an appealing narrative for technologists.

There is no doubt that as a point of inspiration for junior technologists, and a focus for the public these competitions are very powerful. It was natural to consider whether this setting could be useful in a University curriculum (Meeden 1998, Murphy 2001). But of course the demands of a University subject are quite different from the goals of a technology challenge. This paper describes a course incorporating many aspects of the robocup concept designed for fourth year and postgraduate engineers. The lessons of this process may be useful to wider adoption of robot competitions in the University curriculum.

Core concepts

The core curriculum demands of a university level subject have some elements in common with the robot competitions, but there are important differences. My main interest in robot competitions was as an exploration of the research issues of robot teams. The soccer environment is highly dynamic, and provides an ideal testbed for research prototypes. I started with the core concepts for team robotics.

Educationally there are significant challenges. Robotics integrates a broad range of concepts together into a single vehicle. The robot itself will not function unless all aspects are working, and the demands of the mechanics and construction can easily overwhelm the class time. I was searching for a way to concentrate on systems issues but to give some realism to the learning environment.

Figure 1 illustrates the core concepts of team robotics. There are some notable exclusions in this set: apart from simple motion equations, consideration of robot *mechanisms* is not considered. Similarly I exclude energy consumption and electronics for robots. These are incredibly challenging subjects that are worthy of entire courses in their own right. The course was designed to focus on the computer systems aspects of team robotics.

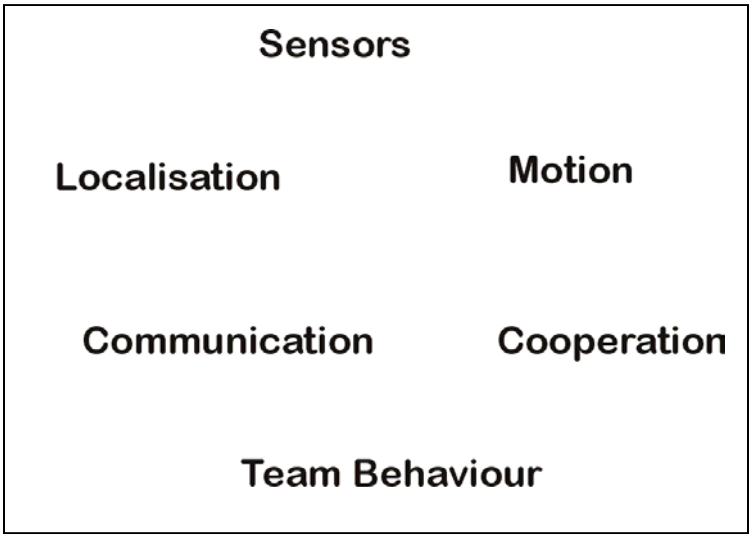

Figure 1: Core concepts for a team robotics subject

Sensors

Team robotics uses small, cheap sensors that do not consume much power. Typically these include ultrasonic beacons and receivers, small radio frequency transponders, bump sensors and similar. The accuracy of these sensors is well known, so performance can readily be simulated. However it is difficult to model complex aspects of the sensors: for example in ultrasonic sensors we only attempt to model the first reflection.

Localisation

Given a set of sensor readings, the robot must determine its location. Localisation is an enormously challenging problem: in the absence of direct beacon readings (eg. GPS) only unreliable sensors such as wheel encoders and ultrasonic reflections can be used. The simulator described here incorporates the localisation problem.

Communication

Robots can only communicate using simple protocols that are economical in their use of energy. A robot team must maintain common knowledge and coordination using very simple means of message exchange. Typically it is not possible to have a lengthy exchange of messages to work out what to do next.

Behaviour Modelling

Robots must behave appropriately in a wide variety of circumstances. To approach the design of this behaviour requires some method of description. Choices range from simple state machines, the specific structure of the subsumption architecture (Brooks) or many other possible choices. A core design activity is developing these descriptions for each robot.

Team Behaviour

The robot team must coordinate to both defend and attack. It is not possible to adopt a highly communicative approach, so coordination strategies are very important.

The educational challenges here are perhaps best summarised by the process of dealing with localisation. We are so familiar with having complete navigation knowledge available from human senses, that it takes some time to understand the degree of "sensor poverty" that a robot faces. There is a distinct conceptual leap required here that is important. At the same time we don't want to spend the whole course just constructing robots.

Simulation or construction?

There is a widely held view that advocates a constructive approach to robotics. Brooks (1999) and the many *artificial life* researchers take this path. There are important philosophical issues here about how you might construct artificial intelligences, but for the moment we focus on educational issues. If we take the point of view that it is only through construction of robots that we are dealing with "real robotics" then what does this mean for students? It means that our concept map can only be learned through actual physical interaction.

This is closely related to the "hands on" argument in education. When we deal with junior school projects and even perhaps high school projects there are powerful psychological arguments. Perhaps it is the case that as we physically develop that actual engagement with physical movement is important. It may well also be the case that the experience for physical interaction is of a deeper and different nature. Certainly to take the concept map and to attempt to construct robots will quickly convince the students of what they do not know in mechanics and energy. But that is surely not the point for learning for adults in a University setting. In a philosophical sense, if we suggest that there are deep aspects of the learning experience that are beyond articulation, then we are heading away from the realms of logic and towards the view that learning is a mystical experience.

So for the course, the question is simply this: can we use simulators to learn the concepts or is it necessary to engage with physical robots? For the moment I am exploring the direction of simulation. In the future it may be possible to test the hypothesis by taking the simulated robots and transferring the designs to physical robots.

JSRSim: approach

There are a wide variety of Robocup simulators. They range from complex multi-node agent based simulators with detailed modelling through to simple abstract strategy evaluators. The robocup simulator league (Robocup 2003) attempts to model a hypothetical humanoid robot team. This simulator even includes some aspects of humanoid anatomy, with head rotation. In contrast, the physical modelling of the robocup "small size league" is incorporated into TeamBots (Balch 1998) for team development. The simulator I have developed (called Java Simple Robocup Simulator: JSRSim) models the physics of the robocup "middle size" league. It incorporates wheeled robots of approximately 30cm diameter with a small junior league soccer ball.

JSRSim (2003) includes the key physical modelling of ball collisions both with the field walls and with other players. The core objects of the software model are as follows. MovingObject encapsulates the physics of the objects on the field. Both the Ball and Robot classes inherit from this class, and Robot extends with sensors including cameras. To create Player style code, the Robot class is extended to incorporate individual strategies and tactics. The Network class incorporates a very simple model of an 802.11 style wireless LAN: there is no attempt to model imperfections in the network. An important simplification is to provide only for circular robots. This is to allow for calculation of the reflection of the ball from robots: it is very difficult to do the reflection calculations for odd-shaped robots.

Figure 2 shows the simulator. There are two modes of operation: practice and competition. In practice robots can be placed and a play sequence recorded. This sequence can then be replayed using a VCR style interface: fast forward, rewind and pause. The competition mode provides for a game of two halves, with a scoreboard. There are no free kicks implemented in the current version (JSRSim 1.1). JSRSim can be run directly on any computer supporting a Java Virtual Machine of JDK1.2 or greater.

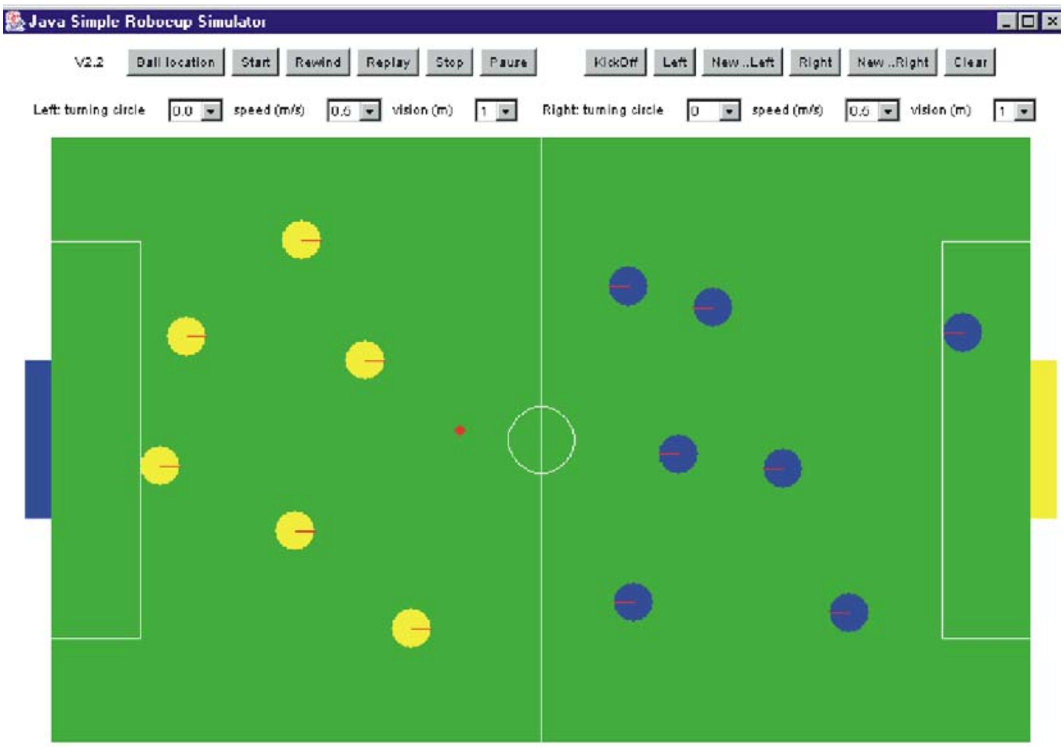

Figure 2: JSRSim Simulator screen view

Since this is the first class use of the simulator, there is naturally a concern to deal with bugs and errors in the simulation. I have adopted an "open source" approach where course credit is offered both for finding bugs and for fixing them. This has been very successful, with many bugs posted and fixed. It is interesting how successful this mode of operation is in working through software problems.

The mode of operation of the subject "Robotics and Control" based around this simulator is in a learner-centered mode (Sparkes, 1999; Kiyoshi 2000). Students work primarily with simulator and interaction with the tutor and lecturer take place continuously. The first task is for students to develop code for localisation of the robots. They execute some standard tests of localisation ability. Following this they prepare a design proposal for their team. This is presented in detail, and they then prepare for the competition. Assessment is weighted roughly 30% for the final team and the remainder of assessment on the technical tasks leading up to the competition. A final essay on team robotics completes the subject. There is no exam.

There are many positive aspects of robot competitions for the curriculum, but we should take care to consider the positives with some important problems and issues.

The course consists of a short series of lectures that introduce the core concepts of Figure 1. This is augmented by a research kit that gives literature references and further guides for study. Significant theoretical material is only treated in the references, and requires the students to explore this material independently. As a fourth year course students are already skilled in these aspects.

Midway through the semester, students are required to present their proposal for team design. This is a critical phase of the subject, and constitutes a large part of the assessement.

Integration

Why are robot competitions so popular? So much of University study is analytical in nature, and pedagogical in approach. But engineers signed up to be engineers primarily to make things. Robotics is inherently integrative in nature: many disciplines and technologies must come together to make things happen. Creativity is essential for competitive success. Perhaps it is a comment on the rest of the curriculum that students flock to these competitions (Boyer, 1998).

Human Team

What sort of teams wins robot competitions? Certainly strong technology helps, but it is often not a deciding factor. The strength of the human team is very important. As is often said: "execution is everything". Often teams with great promise fail due to a clash of egos. Here many valuable lessons can be learned in creating success of human teams operating under pressure.

Setting

A robot competition is a microcosm of some important threads in modern commercial life. Two or three people come together to create something. They have a small budget, a fixed deadline: the date of the competition cannot be moved. Commitment and long hours in pursuit of victory (Manseur 2000) are commonplace. If we take the experiences of a small start-up company or project then there are some similar paths here. The competition is between peers in a public setting. It is not the quiet of the exam room in which the results are decided.

Curriculum hijacking

Given the level of engagement, the real problem here is complete hijacking of the whole curriculum. Students (especially bright ones) neglect their studies and focus entirely on victory. In this setting, a simulator has many advantages. The total hours of effort required to get a team working are much reduced. The costs are dramatically reduced. Nevertheless there is much for the course leader to do in putting competition in perspective.

Assessment through competition is quite different to an exam setting. But there are some similarities: the team must perform on the day and there are no chances for postponement. Since every team performs with the whole class as an audience, it is difficult to plagiarise, as the team behaviour will be recognised. At the same time it is always possible to aim solely for a competition place with little attention to the course concepts or outcomes. Design of assessment is quite difficult but critically important.

If competitions are public events then pressure to get the highest place will become intense. Even worse is when the media becomes involved. My experience of the private course competition is that a private competition can be fairly friendly. For all these reasons I restricted reward for a place in the final standings to approximately 10% of total final subject mark. The other criteria included: originality of team proposal, quality of implementation, documentation and testing reports.

Overall results of the course were interesting. Since the course demanded strong commitment, the team results were quite strong. The highest level teams were very impressive. Balanced against this, there was a distinct "two peaks" to the final result, indicating that weaker students struggled to stay with the course. This is an ongoing challenge for the learner-directed approach: how to recognise difficulties early and provide assistance for students who are having difficulty. In this case the presentation of a design proposal was not a good indicator, and it remains to create better pathways through the subject material.

In design of the course, the approach was to minimise the effect of the competition, and on reflection I will continue to further minimise the role.

Conclusion

Robot competitions have much to offer educationally. If the competitive aspects can be kept in perspective, then there is a fertile learning environment for students. It offers a highly dynamic learning experience that has a healthy mix of competition and disclosure. My experience so far is that a simulated environment can produce strong results in understanding the core concepts without the incredibly difficult workload of constructing physical robots. The approach described here attempts to balance the positives of competition with the demands of the pursuit of excellence in robot team development. I expect that we will see a growth in the use of robot competitions in the University curriculum as we continue to grapple with these issues.

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Acknowledgements
My thanks to the students of eeet2165 for ongoing contributions to the development of the simulator.

Problem oriented teaching in electric power: some experience and new trends in Tasmania and Ukraine

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Abstract: *The increasing power and availability of software tools used for power system analysis have already changed the way power system subjects are taught and learnt. This paper describes curriculum issues of power systems for third and fourth year power students of the University of Tasmania with an emphasis on problem-oriented teaching. It also introduces issues related to power engineering education in Ukraine. Problem-oriented teaching helps to reach a sound understanding of a broad range of topics in power systems and make the syllabus interesting and attractive to students. The impact of changes in the power industry to the problem of women in engineering is considered.*

Keywords: *Power Engineering Education, Problem-Oriented Teaching, Computer Applications in Power, Expert System Shell.*

Introduction

The word "problem" has a number of meanings, however problem solving, in general, can be considered as finding the most effective course of action among a number of alternatives. Any condition of a given system is the problem situation when a student experiences intellectual difficulties due to the shortage of information and/or time and cannot achieve a goal applying a familiar technique. It causes a student to seek a new approach to the problem and gives rise to his or her creative mental activities. Therefore, problem-oriented teaching aims to develop the creative mentality and results in more logical and professional thinking (Gibbs and Habeshaw, 1989; Lesgold, 1978). However, any logical mentality should be based on a practical basis. It means that practical skills and knowledge should be considered as a criterion of the human professional mentality (Green, 1991).

It is of vital importance that power students acquire knowledge and hands-on experience to deal with real practical problems in power system operating and planning. They need to learn theory in order to make their own decisions in solving a particular problem.

The aim of the final year power systems course is to instil confidence and understanding of those concepts of power system analysis that are likely to be encountered in the study and practice of electrical power engineering. The approach taken is to develop critical thinking of a student in a broad range of topics in the area of power systems.

The authors have taught a variety of power system courses for students with different backgrounds and experience in electrical engineering. There have been students with extensive experience in computer applications. But there have also been students with little experience with computers. The opportunity of teaching the power systems course to students from such a wide range of exposure to computers has been a learning experience for the authors on how to best introduce students to computer applications in power.

Course Objectives

The primary objective of the final year power system course is to provide students with an opportunity to solve a number of practical problems in power systems. It is only through hands-on experience that students can obtain a real understanding of power systems.

"I hear and I forget,
I see and I remember,
I do and I understand".

This old Chinese proverb can be used as a guide for introducing students to power systems design and operation. First students are introduced to some major concept, such as load flow solutions, followed immediately with a demonstration of power flow studies in a small four-bus power system. When the students have mastered load-flow analysis, they should then perform load flow study on a five-bus power system and find bus voltages and flows of megawatts and megavars. The students are also required to study the system behaviour under different operating conditions and explain results obtained. The style of presentation of the course material which includes lecture, demonstration and actual problem solving gives students an understanding of the basic concepts.

In addition to solving small problems for clarifying power systems concepts, it is extremely important to give the students an opportunity of solving complex practical problems existing in power systems design and operation. This work is included in a course project.

It is not practical to achieve all the objectives described above with a single one-semester course unit. It is necessary to prepare students by giving them a preparatory course in power systems. In the University of Tasmania, this course unit is designated as *Power Systems 1* and is offered in the third year. The second unit, *Power Systems 2*, is offered in the final year. The two units together form the whole body of *Power Systems* for students taking the Power option. In this paper, therefore, both the course units will be described.

Major topics in Power Systems One

This basic course which is compulsory for all Electrical Engineering students is offered in the third year. The topics covered are:

- Revision of AC circuits;
- Per unit quantities;
- Equivalent circuits of power system components;
- Voltage characteristics of loads;
- Control of voltage and reactive power;
- Load flow analysis;
- Symmetrical Fault analysis;

- Safety and protection in industrial power plants;
- Harmonics and Quality of Power Supply;
- Direct Current Transmission.

Major topics in Power Systems Two

In order to achieve the previously discussed objectives, the following major topics are included in the course:

- Asymmetric Fault calculations;
- Admittance and impedance models and network calculations;
- Load-flow solutions;
- Fault calculations using the bus impedance matrix;
- Selection of circuit breakers;
- Economic operation of power systems;
- Power system security;
- Reliability analysis of power systems;
- Intelligent systems applications to power systems.

An important factor in teaching this unit is the use of Expert Systems. A commercially available Expert System software named *Level5 Object* is used by the students to simulate the operations of a power system. For example, students are required to take appropriate actions to improve the voltage profile by adjusting transformer taps, changing generator voltages and switching reactive power compensators. Thus problem-oriented teaching together with the expert system application helps to reach a sound understanding of a broad range of topics in power systems and make the syllabus interesting and attractive to students.

Power engineering education in Ukraine

A decline in the popularity of power engineering education has been observed in Ukraine during the last several years. The main reason for this general decline in the enrolment of power engineering departments is the slowing-down of the power industry sector of the national economy.

The power sector of Ukraine has 50.9 gigawatts (GW) of installed capacity. It is capable of producing twice its electricity needs. Nevertheless, only 163,600 GWh of electricity was produced in the last year. (For comparison, according to published data (The Electricity Supply Association of Australia Limited, 2003), the total electricity generation in Australia last year was about 199,000 Gwh, while power generation plants installed capacity was only 42 GW). Total electricity consumption in Ukraine has reduced from 216,700 GWh in 1992 to 123,300 GWh in 2002. This trend in the power industry has had a significant impact on the labour market. Unemployment among power engineering graduates has increased.

However, Ukraine still plays an important role as a critical transit centre for exports of cheep Russian electricity to European energy markets. Russia inherited a powerful high voltage transmission network from the Soviet Union. The network includes a backbone of 220-750 kV transmission lines with overall length of about 21,700 km and 131 substations with total installed capacity of about 76,785 MVA. However, due to the network's inefficiency, especially in the area of automation, a significant amount of transmitted power is wasted via line losses and outages. On the other hand, the onrush of communication technology and the latest developments in digital equipment allow us to renew an old-fashioned domestic automation. The world biggest producers of industry-oriented digital and communication equipment, like SIEMENS, ABB, ALSTOM have come to Ukraine recently. They have brought new technology, and with that introduced new prestigious job opportunities for Ukrainian well-educated electrical engineering graduates.

In these conditions, most Electrical Engineering Departments and Schools of Ukrainian universities try to enlarge their educational frames by new courses. In particular, these courses are related to modern digital protection systems, new intelligent electronic devices, communication industry protocols and equipment, new interconnection standards, state of the art computer applications in power systems, Computer-Aided Design (CAD) systems, Internet Protocol (IP) technologies, artificial intelligence methods and tools.

Traditionally most electrical engineers graduates from Ukraine universities in three main specialties: power systems, power plants and power delivery. They have some small differences in the forth and fifth years courses. In order to compare power-engineering programs with University of Tasmania we describe the main courses, which are taught in the most prestigious universities in Ukraine.

Second year courses:
- Chemistry;
- Theoretical mechanics;
- Engineering Drawing;
- Physics;
- Theoretical Principles of Electrical Engineering;
- Higher Mathematics.

Third year courses:
- Fundamentals of Law;
- Industrial Electronics;
- Applied mechanics;
- Power Engineering Mathematics;
- Power Engineering Economics;
- Algorithm Presentation of Power Engineering Problems;
- Power Engineering Installations of Power Stations;
- Electrical Machines;
- Transients in Electrical Systems: Part 1.

Fourth year courses:
- Transients in Electrical Systems: Part 2;
- Programming and Application of Electronic Computers;
- Electrical Systems and Networks;
- Safety Measures;
- Electrotechnical Materials;
- High Voltage Engineering;
- Electrical Instruments and Electrical Measurements;
- Models of Optimising Development of Power Engineering Systems;
- Power Engineering Systems Operation;

- Electrical Part of Station and Substation;
- Electrical Systems and Networks;
- Protective Relays and Automation of Power Engineering Systems;
- Programming and Application of Electronic Computers.

Fifth year courses:
- Principles of Scientific Research and Engineering Creativeness;
- Organisation and Planning of Production. Business Management;
- Student's Scientific Research Work;
- Fundamentals of organisational and educational work on the work Collective;
- Special Questions of Electrical Systems;
- Long Distance Power Transmission;
- Student's Scientific Research Work;
- Optimising Conditions of Power Engineering Systems;
- Automatic Control of Power Engineering Plants;
- Organisation and Planning of Production. Business Management.

Before 1990, the power industry in Ukraine was relatively strong. As a result, many jobs in power engineering were related to the design of new power plants, power substations and transmission networks. This may explain the fact that about half of power engineering students were women. Design-engineers and draftswomen were a popular choice among women at that time. Unfortunately in the last decade, due to the decline in the power industry, the overall demands for such jobs are decreasing. The majority of job opportunities are now related to servicing and supporting existing equipment and mainly are man-oriented.

Conclusions

In the last decade, there has been a general decline in the enrolment of power engineering students both in Australia and Ukraine. Some of the universities have closed their power engineering disciplines. The University of Tasmania has attempted vigorously to beat the slump. To stimulate student interest, problem-oriented teaching has been introduced. An introduction of artificial intelligence on the course has created some additional interest. The course structure geared to problem-oriented teaching should have a positive influence in the turnaround of the existing trend.

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On the teaching of computer programming to adults

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Abstract: *Reflections on the problems faced in teaching novice computer programmers are presented in an informal, stream-of-consciousness manner, based on field experience and folk wisdom acquired with RMIT Technical and Further Education (TAFE) students. Questions of a diverse nature are raised on research strategies to pursue for pedagogic innovations in this area.*

Keywords: *teaching innovations, novice computer programmers*

An IT academic once remarked to me, in jest, that computer programming is as boring as "bat shit". Programming may appear to be a tedious activity to the spectator, but why is this so? The very act of writing a computer program (or program code) is a task that involves reframing an often ill-defined problem as a system of interlocking text-based components consisting entirely of sequence, selection and repetition statements. (Sequence statements are command-like sentences that initiate one action after another in order. Selection statements are also command-like sentences that are used for making a choice between alternative actions. Finally, repetition statements are - you guessed it - command-like sentences that are used for performing some set of actions over and over, usually until some condition is encountered that forces a stop to it.) Repetition is an essential part of any piece of software in the making. Needless to say that "repetitive" is a synonym for "monotonous" which in turn also means "boring"! Facetious logic aside, perhaps the reason for the dreary reputation of programming as a "nerdy" pastime is due to how it is currently taught to adult students at universities and colleges.

Soloway (1986) states that textbooks used in software development courses for novices focus on the syntax and semantics of constructs in a programming language. After 17 years nothing has really changed, with the syntax and semantics approach still being the way programming is taught at most institutions today. The syntax of a computer language is the set of structural patterns that individual tokens of the language must adopt to form valid statements in a program. Semantics deals with the meaning of these component statements and the program as a whole. (I usually describe the distinction between syntax and semantics to my students by first writing Noam Chomsky's famous sentence "*Colourless green ideas sleep furiously*" on the whiteboard (Chomsky, 1957). This sentence appears to sound right in that we can tell that it's a properly formed sentence. Adjectives are used OK. Nouns and verbs are placed in the right order. This is syntax at play. But the whole sentence makes no logical sense and has no meaning. That's semantics or a lack of it!)

To attain computer literacy, students of programming are shown the meaning of the syntactic components of a computer language and how they are individually used in very simple examples (in a manner similar to that of a phrase book for travellers.) They are then given relatively straightforward practical exercises to undertake so that their newly acquired knowledge of syntax can be put into practice. The very first program that students are taught to write is one that simply displays the sentence “Hello World.” on screen. By convention, this is generally the first program that most novice programmers write, regardless of what the computer language may be. Guzdial and Soloway (2002) maintain that this opening approach is symptomatic of the outdated view of computing and students that many IT educators have. In an age of affordable multimedia computing for the masses, it is no wonder that students find it difficult to be inspired by merely displaying a line of text. Many students today are part of the “Nintendo” and “MTV” generation of audiovisual aficionados and this is a possible contributing factor to IT education being dubbed by some to be “tedious and dull” (AAUW, 2001).

Guzdial and Soloway (2002) advocate a “multimedia-first” approach to the teaching of computer programming. In other words, inspire the students by getting them to play with sounds and simple animations. This of course assumes that students are of sufficient technical sophistication in the first place. Novices may be able to grasp writing a “Hello World” program because of its sheer simplicity but going beyond this level is another story. It is here that most students fall over because they can’t put the previously learned pieces of syntactic theory together into one program whole. Learning to program is like learning to ride a bicycle, I often tell my students. I can show them the mechanics of the theory in class but only the students, on their own, can be in control of how soon they can ride and not fall over.

Lots of practical experience is involved in the path from novice to expert programmer. The prevailing philosophy of most IT educators that I know is that the best way to learn how to write code is to write code. As Thomas Edison said: *“Genius is 1% inspiration and 99% perspiration.”* Programming students are usually required to submit several programming assignments for assessment during the course of a semester. Once again, these are meant to gauge a student’s ability to comprehend the theory and apply it in a practical context. This is the way computer programming is taught at most academic institutions at post-secondary level today and it has probably been carried out in this fashion since the dawn of IT.

The learning of software development mainly occurs in a computer laboratory environment with PCs on benches in fixed positions facing a whiteboard and projection screen at the front of the room. The décor is Spartan and not at all aesthetically pleasing to say the least. The isolation enforced by the individual workstations doesn’t facilitate context-based learning. Situated cognition encompasses the latter approach in that learning is considered to be primarily social in nature (Hansman, 2001). Communities of shared practice facilitate both the incubation and transfer of knowledge. Sheard and Hagan (1999) outline the design of a new learning environment to assist weak introductory programming students at tertiary level. The “environment” discussed is the style of delivery not the actual physical surroundings of learning, which presumably are immutable for technical reasons. Procedures for assessment, assignment work, tutorial classes, group exercises and lectures are summarised. In the latter, role-playing activities are included to sustain interest in the proceedings.

To exploit the benefits of context-based learning, it would perhaps be a better idea to experiment with “pair programming” in a lab environment (Williams and Kessler, 2000). This is a practice in which two programmers work side-by-side at one computer, constantly collaborating on the same piece of work. The technique is primarily aimed at professionals, who claim significant increases in productivity and quality of software products after its acceptance. It could be adopted in an educational context but it might also be seen to raise the risk of plagiarism even more so the technique could prove to be politically unsound at many academic institutions.

In the TAFE sector within the RMIT School of Business Information Technology, an introductory programming course generally consists of a one hour theory lecture per week and four hours of practical work in a computer laboratory, spanning a 15-week academic semester. It must be said that teaching programming using a lecture format isn't the ideal approach. Most students are bored to tears by lectures that dwell on technical minutiae, such as where to place a semicolon in a computer language statement. But to master programming one must have the patience and fortitude to tame the proverbial "devil in the detail". More learning takes place in the labs where students engage in practical activities and the instructor acts as a mentor, almost in a "master-apprentice" relationship. One of the problems with computer programming is that it has almost always been in an identity crisis, much like the discipline of computer science itself (Nwana, 1997). Is it a science or an art or a craft or a skill?

No one has yet provided a definitive answer.

Computer programming is an adult activity, if not by definition then by practice. As Perlis (1982) notes with tongue-in-cheek: *"Perhaps if we wrote programs from childhood on, as adults we'd be able to read them."* The uninitiated may cling to urban myths that children or young teenagers can become adept at the skill but that is primarily due to sensationalist reporting by the media over-inflating the prowess of fledgling hackers, who often perpetrate their acts using a "recipe-based" approach. No, the kind of programming that I am referring is an offshoot of general problem solving from first principles, one that requires the representation of some limited domain of reality with meticulous precision and attention to detail. One has to be able to closely analyse a real-world problem, understand it so as to make explicit that which was implicit, and then translate all of this into a language that a "dumb" computer can comprehend. The computer is merely an external cognitive tool that amplifies the abilities of the person that programs it. So, if you put garbage in, you can only ever expect garbage out. Perlis (1982) states: *"You think you know when you learn, are more sure when you can write, even more when you can teach, but certain when you can program."* This feeling of certainty is a hallmark of the skilled programmer, even though it is generally accepted that error-free software is the mythical exception rather than the norm.

Computing programming is often dubbed a very difficult activity in the literature (e.g., Pane, et al, 2001). To quote Perlis (1982) once again: *"Most people find the concept of programming obvious, but the doing impossible."* Most consumers would appreciate the idea of programming a VCR to tape a TV show but anecdotal evidence would suggest that actually doing it is unachievable by the masses. Otherwise, what else would explain the near ubiquitous "flashing display" on most VCRs in service or the invention of G-code? And the programming of a VCR is vastly simpler than programming in the C++ computer language, say. Some of the difficulty in learning how to program a computer is acknowledged as being inherent to the skill itself. However, part of this complexity could be due either to the poor design of languages or to the fact that it is not taught in the right way (Pane, et al, 2001).

Dijkstra (1989) laments at the use of comfortable metaphors and mundane analogies to teach programming, frowning upon the continued description of the new with yesterday's vocabulary. As Dijkstra (1989) contends: *"Coming to grips with a radical novelty amounts to creating and learning a new foreign language that cannot be translated into one's own* *mother tongue."* He believes that students should be taught the joy of rigorous thinking by being shown the beauty of mathematics. Formal methods derived from mathematics could serve as a *lingua franca* to facilitate the teaching of programming in an optimal manner. By developing the intellectual stamina to face uncomfortable truths, the novice can then begin to tame the complexity that is computer programming. It's the "castor oil" approach to education: This medicine is good for you; so it tastes bad but given time you might get used to it.

Devlin (2001) is also of the opinion that mathematics is important for budding software engineers. Abstraction is difficult for the human brain to cope with and this is what software development is fundamentally all about. As a species we evolved primarily to interact with the concrete structures of our physical environments not the virtual ones exemplified by computer programs. Mathematical thinking reinforces repetitive learning of abstractions. Many TAFE students, mature-age or otherwise, have little or no training in higher-level mathematics. Indeed, the students with no mathematical background generally exhibit the most difficulty with computer programming. Monroe and Orme (2002) provide some guidance on how to expand the mathematical vocabulary of students; however their advice is for primary school teachers. What should probably be a prerequisite for the novice programmer is some exposure to advanced mathematics beyond basic arithmetic, such as a palatable introduction to discrete mathematics, but this would be a syllabus policy decision outside of the authority of teachers in the trenches.

Soloway (1986) writes that research of the time indicates that computer language constructs do not pose major obstacles for novice programmers. The real problem is that learners don't know how to put the pieces of the jigsaw together in composing and coordinating components of a program. They may understand fragments of program code on their own but have enormous difficulty assembling these parts into a working whole. Amazingly this is the same remark that I often get from adult students today! The focus on instruction of the syntax and semantics of programming language constructs is wrong according to Soloway (1986), as it promotes an undue emphasis on the finished program as the final result of the whole process. A program is a set of instructions that transforms a computer into a mechanism that controls how a real-world problem can be solved. But a human being – the programmer – needs to have an explanation as to why the program solves the particular problem.

According to Soloway (1986), learning to program should be viewed as learning how to put together mechanisms and how to compose explanations. Accentuating the theoretical content of an introductory course and making the underlying abstractions of programming explicit, in addition to covering the rules of programming discourse, can achieve this. In other words, students should be shown what programming has in common with other problem solving tasks. It should be stressed to novices that programming is a design discipline with the output of the process being an artefact that performs some desired function (i.e. a "mechanism"). The trail of information in creating this artefact is an "explanation". It's a new philosophy for interpreting the act of programming. Of course, I can think of no contemporary introductory course or textbook that currently adopts this pedagogic strategy. Once again, the reasons are probably political.

Eliot Soloway is one of the pioneers of "software psychology", a neglected field of IT that was partially inspired by the ideas espoused in Gerald Weinberg's landmark 1971 book "The Psychology of Computer Programming" (Weinberg, 1971). This text was one of the first to deal with programming as a human cognitive activity. In fact, it's probably one of the only

existing books still in print that does so, as most texts tend to dwell excessively on the technical aspects of programming. In the early 90's, during a stint as a Lecturer in Software Development at Monash University, I was motivated by Weinberg's book to develop a dedicated postgraduate course in this vein. Except it
was not called "Software Psychology" because that would have raised the ire of the Psychology academics. Rather, it was given the more innocuous title of "Behavioural Issues in Software Development". Arguably the first and last course of its type in Australia, it was too introspective in a psychological sense for the powers-that-be who championed courses that dealt with the latest technical fads of the time, and it died an unceremonious death after only one semester. Without postgraduate courses such as this, university IT departments cannot hope to persuade students to do research in a similar area. And without a critical mass of research students in software psychology one cannot hope to expect findings that could eventually make life easier one day for the rank-and-file teacher of programming.

How can the teaching of programming be improved? I believe that one has to look at computer languages from a fresh, new perspective before anything else can be done. In April 2002, I gave a presentation at the 6th Conference of the Australasian Cognitive Science Society entitled "*Cognitive Dynamics of Programming Languages.*" Are computer languages "tools" akin to the user interface of a machine or are they artificial dialects with all or some of their inherent linguistic properties? My talk addressed the issue of whether the acquisition of computer languages actually changed the way people could think.

"*Programming is the new Latin*" was the slogan that many an early computing teacher espoused, according to diSessa (2001), but such a notion also lead to an "antiprogramming" backlash (e.g., Pea and Kurland, 1984). It was still unclear as to whether learning to program made people more logical and powerful thinkers, as it was once believed that the learning of Latin would do. However, the many arguments that went to and fro ignored the work of amateur linguist Benjamin Lee Whorf…

The concept of linguistic relativity (also know as the Sapir-Whorf hypothesis) suggests that natural languages influence the way their speakers think (Whorf, 1956). It could be argued that programming languages share more than just metaphoric links with natural languages. For example, both are constructs dictated by the frameworks of syntax and semantics, albeit a computer language is devoid of speech and exists only as a form of writing. Could this be a reason for why learning to programming is so often dubbed a difficult task?

Perhaps adults find it so hard to learn their first programming language because it is more like a natural language than most computer scientists would care to admit. It has been taught like it was a physical tool to master when the mode of instruction should have been similar to that required to gain fluency in a second tongue. Gaining competency in a second natural language as an adult learner has always been deemed to be challenging. But at least the subject matter is considered from a linguistic angle for the pedagogic approaches involved in language learning. I propose that we should teach programming languages as if they were a second natural language to be acquired. The first step should be to teach students to read before they can write. Remember that computer languages have no analogue to speech so novices can't learn how to talk first. Their goal is to become fluent in the composition of complex programs, something vaguely similar to writing a novel. Now, one would not aim to write a great novel until one has at least read a few. Same idea here: read good program code first, identify the bad stuff and then go on to do the actual creative writing.

Zeller (2000) advocates the adoption of an automated system to allow students to read, review and assess each other's programs in order to improve quality and style. Of course, this presupposes that students have learned to write code first. To encourage the reading of code, I would like to see the development of computer program "literature", a library-based resource of good and bad examples that exists solely for critical analysis by novice and expert alike. Knuth (1992) outlines the technical details of what the paradigm of "literate programming" would entail. Basically, it would involve the development of a technological infrastructure that would allow one to curl up in a chair by an open fireplace while reading a good computer program. This has yet to be convincingly realised in the practical sense.

In what other way can software be treated as literature? Book groups are a relatively recent phenomenon. In these gatherings interested parties discuss the merits or otherwise of a particular novel. Hagan and Sheard (1998) discuss the value of discussion classes for teaching introductory programming. Preliminary findings indicate that such classes, which are held in rooms without computers, lead to an improvement in student results. The tutor's responsibility in such a class is to incite debate about programming concepts rather than simply spoon-feeding answers. Once again, the clientele in the situation described are tertiary students.

Postgraduate courses in education are far too generic in their subject matter for specialist practitioners such as IT academics. Teachers in different disciplines face different, unique problems. One standard set of pedagogic theories can't possibly fit all situations. Programming teachers would benefit immensely from undertaking a graduate diploma in education that actually focused in part on strategies derived from software psychology meshed with contemporary pedagogic theories. This could be achieved by offering an elective via team teaching in a generic diploma: one member from an education faculty and the other from an IT faculty. The latter individual would have to be well versed in software psychology as well as the nuts-and-bolts of computer programming. Indeed, an interdisciplinary research venture involving academics from IT, education and psychology may be the best approach to demystify the art of computer programming for everyone.

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Academic performance and persistence of on- and off-campus engineering and technology students

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Abstract: *A study of more than 9000 unit enrolments in an Australian engineering program found that: the off-campus withdrawal rate was close to twice that for on-campus students; whether a student withdrew or not was highly correlated to mode of study; the rate of withdrawal was significantly different between the two student groups; the grade distribution for completing students was significantly different between the two groups; the mean final grade was significantly higher for off-campus students; the failure rate for off-campus students was significantly lower; and the overall wastage rate (withdrawn rate plus fail rate) was significantly higher for off-campus students.*

Keywords: *academic performance, student persistence, off-campus study*

Introduction

Flexible delivery of engineering and technology education is now an essential component of the engineering education scene, catering for significant numbers of students who cannot attend traditional, full-time, on-campus studies. In Australia, most engineering and technology undergraduates studying in the off-campus mode are mature age students. The literature suggests that:

- engineering students have one of the highest withdrawal rates of all disciplines;
- off-campus students have higher withdrawal rates than on-campus students; and
- mature age students have higher withdrawal rates than conventional entry students.

This suggests that off-campus mature age engineering students would have a relatively high rate of withdrawal from their studies prior to completion. The literature also suggests that for those students who persist (don't withdraw), off-campus students have a better academic performance than their on-campus counterparts.

The engineering and technology programs at Deakin University in Australia cater for both on-campus conventional entry students and mature age off-campus students. Anecdotal reports from academic staff tended to support the general withdrawal and performance characteristics reported in the literature. However, no formal research had previously been conducted, and a cursory inspection of student academic records provided some counter examples to the accepted wisdom. To gain an objective understanding of the withdrawal and performance characteristics of both on- and off-campus students in the engineering and technology programs at Deakin University, a study was undertaken on more than 9000 unit enrolments over the period 1996 to 2000.

Student persistence and academic performance

A 1968 study in the United Kingdom found that engineering and technology students had one of the lowest rates of course completion in the normal course time (68 percent) and the highest rate of non-completion of studies (21.8 percent) (University Grants Committee, 1968). Seymour and Hewitt, in an investigation of why United States science, mathematics and engineering (SME) students swapped study majors, found that 38.1 percent of commencing engineering students swapped out of a SME study major (Seymour & Hewitt, 1997). In a major United States study Astin reported that only 43 percent of first-year engineering students successfully completed their studies (Astin, 1993). Dobson, reporting on first-year progression rates in Australian universities in 1995, found that 22 percent of commencing engineering students where not successful in completing the first year of their studies, one of the lowest rates of all disciplines (Dobson, 1999). Shah and Burke using Australian student data in 1996 concluded that, 'An Engineering student has the least chance of completing a course…' (Shah & Burke, 1996). Urban et al., in a 1997 review of Australian students who commenced their studies in 1992, found that particular fields of study, including engineering, contributed negatively, irrespective of student characteristics, to the probability of the student completing their studies (Urban et al., 1999).

High withdrawal rates (30-80 percent) are historically reported for distance education programs (Rekkedal, 1972). Glatter and Wedell in 1971 suggested, 'The purely quantitative data on wastage in correspondence courses indicates two things: that it is much higher than would be expected in full time oral courses; and that it is particularly heavy in the early stages of a course...At examinations, correspondence students seem to do as well or better than their counterparts taught the same subject orally.' (Glatter & Wedell, 1971) McIntosh and Morrison reported on two Australian studies in 1965 and 1967 that showed an average 33 percent withdrawal rate for first year correspondence students, with only 34 percent eventually graduating, and a withdrawal rate of 34 percent for correspondence students compared to 12 percent for full time students (McIntosh & Morrison, 1974). The same source reported on student demand, progress and withdrawal in the first four years of operation of the Open University of the United Kingdom (OUUK). In 1971, 19 percent of students provisionally registered for study did not complete their final registration and, of those who did, another 19 percent withdrew prior to their course examination (McIntosh & Morrison, 1974). Woodley and Parlett reporting on OUUK students in 1982 found that 28 percent of provisionally enrolled new students did not complete their final registration, for all students finally enrolled 24 percent withdrew prior to their course examination and that the failure rate for those who sat their final examination was 6 percent; giving an overall 'wastage' figure of 29 percent of all enrolled students (Woodley & Parlett, 1983). They also found that in 1981 'technology' courses at the OUUK had the highest wastage rates of all first and second years courses, that for all students the highest drop-out rate occurs in the first two levels of study and that student drop-out rates in comparable international distance education institutions varied from 20 to 71 percent (Woodley & Parlett, 1983). Urban et al. in the 1997 review of Australian students noted above found that full-time students had the highest completion rate (73 percent) while external students had the lowest completion rate (37 percent); the mode of study was significantly correlated to academic outcome (Urban et al., 1999).

Many off-campus students are also mature age students; electing to study in the off-campus mode so as to be able to combine their work, study, family and/or other commitments. In a 1980 review of international literature on the academic performance of mature age students, Eaton reported that mature age students have comparable failure and withdrawal rates to conventional entrants, but achieve higher academic results than their younger counterparts (Eaton, 1980). In a 1980 review of Australian literature on the academic performance of mature age students, Eaton and West reported that mature age students perform better than conventional entrants do (fewer failures and higher average grade), but have a higher dropout rate (Eaton & West, 1980). Shah and Burke using Australian student data in 1996 concluded that the probability of course completion decreases with the age of the student and, in particular for engineering, 'A student who commences a course...in Engineering at an age of 24 years or more has a 50% or less chance of completing it.' (Shah & Burke, 1996)

The Deakin University engineering programs

The Deakin School of Engineering and Technology offers three year Bachelor of Technology (BTech), four year Bachelor of Engineering (BE), Masters and Doctoral engineering programs in flexible delivery mode. The undergraduate programs are delivered in both on-campus and off-campus modes. Conventional entry students would normally undertake these programs on-campus, full-time; with some of these students taking part or all of their studies part-time and/or off-campus in later years to better suit the employment or other personal circumstances. Mature age students may study the programs on-campus, full-time, but many elect to study off-campus and/or part-time because of employment or other commitments.

The flexible delivery and articulated entry characteristics of these engineering programs mean that students studying in off-campus mode form a significant proportion of the total student population at the Deakin School of Engineering and Technology. Hence it is important for the School to understand the characteristics and performance of this student group, along with those of the conventional entry student group studying on-campus. Previous research in the School identified that off-campus students are predominately mature aged at the commencement of their studies (Briggs, 1995), with a significantly different age distribution to their on-campus counterparts (on-campus mean = 18.5 years, standard deviation = 2.1; off-campus mean = 34.4 years, standard deviation = 7.2) (Palmer, 2001b). In the School there was anecdotal evidence that off-campus students had higher dropout rates, but those who persisted performed better academically than on-campus students. It was considered important to determine objectively the rates of persistence and academic performance of the two principal classes of students in the School. This was not intended to fuel any debate about which was the 'better' student group or the 'better' mode of study. Rather, it was intended to assist the academic staff of the School to understand the different characteristics of these two student groups so that teaching and learning strategies could be best adapted to their differing circumstances.

Methodology

This research study aimed to discover quantitative relationships between academic performance and mode of study via a longitudinal statistical analysis of student academic results in a representative cross section of study units from the undergraduate engineering programs at Deakin University. Ten units of study were selected from the first two years of the Deakin engineering programs. The units were chosen because they were core units common to all or most of the engineering disciplines on offer, hence capturing the full diversity of the major study areas selected by students, as well as having relatively large enrolments to enhance the validity of statistical comparisons. Various units included significant laboratory work, computer programming, mathematical problem formulation and solution, case study investigation, essay/report writing, spatial visualization and CAD drafting. The list of units included in the study and their nominal year level are included in Table 1.

Unit code	Unit name	Year level
SCC172	Basic programming concepts	1
SCM113	Discrete mathematics	1
SCM124	Introduction to mathematical modelling	1
SCM228	Engineering mathematics	2
SEB121	Fundamentals of technology management	1
SEB221	Managing industrial organizations	2
SED102	Engineering graphics and CAD	1
SEM111	Materials 1	1
SEM212	Materials 2	2
SEP101	Physics 1A	1

Table 1: Units included in the research study

From the university student information database, enrolment and results data were downloaded for each of the units identified in Table 1 for the years 1996 to 2000 inclusive, and the following statistics were compiled for each unit in each year:

- number of students enrolled - all/on-campus/off-campus;
- percentage of enrolled students withdrawn - all/on-campus/off-campus;
- chi-square test of independence of study mode and withdrawn status;
- large sample inference test of the proportions of withdrawn students in the on- and off-campus groups;
- excluding withdrawns, chi-square test of homogeneity for the distribution of final grades (fail/pass/credit/distinction/high distinction) between on- and off-campus students;
- excluding withdrawns, mean final score - all/on-campus/off-campus;
- excluding withdrawns, one-way analysis of variance (ANOVA) test of mean final score for on- and off-campus groups;
- excluding withdrawns, percentage of students who failed to pass - all/on-campus/off-campus;
- excluding withdrawns, large sample inference test of the proportions of failed students in the on- and off-campus groups;
- percentage of enrolled students 'wasted', that is, the percentage of withdrawn and failed students combined; and
- large sample inference test of the proportions of wastage in the on- and off-campus groups.

For each unit the data for the five years 1996 - 2000 was combined and the above statistics were re-compiled to provide an overview of each unit. Finally, all data collected was combined and the above statistics were re-compiled to provide an overview of student performance in the engineering programs at Deakin University. For this research project, a statistical significance level of 0.01 was used.

Results

The data collected represents 9245 student enrolments in individual units of study (subjects). 5922 (64.1 percent) of these enrolments were on-campus students and 3323 (35.9 percent) were off-campus students. Table 2 presents the results compiled for each unit from the combined summary unit data over the period 1996 to 2000. Any significant deviation in the data for particular years compared to the combined summary results is noted in the Discussion below. Table 2 also presents the overall results compiled from all of the collected data combined. Where there is a statistically significant difference between on- and off-campus results ($p \leq 0.01$) the data pair are shaded. Figure 1 presents the distribution of final grades for on- and off-campus students based on all data combined.

Unit	Study mode	Enrolment (no.s)	Enrolment (%)	With-drawn	Mean score	Failed	Wastage
SCC172	On-c	641	62.9 %	24.5 %	57.2 %	22.3 %	41.3 %
	Off-c	378	37.1 %	48.7 %	60.1 %	23.3 %	60.6 %
	All	1019	100.0 %	33.5 %	58.0 %	22.6 %	48.5 %
SCM113	On-c	615	71.9 %	20.5 %	60.4 %	20.9 %	37.1 %
	Off-c	241	28.1 %	36.5 %	60.3 %	24.2 %	51.9 %
	All	856	100.0 %	25.0 %	60.4 %	21.7 %	41.2 %
SCM124	On-c	672	66.5 %	32.6 %	51.3 %	33.6 %	55.2 %
	Off-c	339	33.5 %	59.9 %	54.1 %	29.4 %	71.7 %
	All	1011	100.0 %	41.7 %	51.9 %	32.6 %	60.7 %
SCM228	On-c	387	56.8 %	23.0 %	58.4 %	16.8 %	35.9 %
	Off-c	294	43.2 %	32.0 %	63.1 %	13.5 %	41.2 %
	All	681	100.0 %	26.9 %	60.3 %	15.5 %	38.2 %
SEB121	On-c	697	75.3 %	26.7 %	61.0 %	17.2 %	39.3 %
	Off-c	229	24.7 %	52.4 %	65.3 %	14.7 %	59.4 %
	All	926	100.0 %	33.1 %	61.7 %	16.8 %	44.3 %
SEB221	On-c	515	49.8 %	26.2 %	63.7 %	12.4 %	35.3 %
	Off-c	520	50.2 %	40.0 %	65.8 %	12.2 %	47.3 %
	All	1035	100.0 %	33.1 %	64.7 %	12.3 %	41.4 %
SED102	On-c	782	69.6 %	38.0 %	55.3 %	26.4 %	54.4 %
	Off-c	341	30.4 %	57.5 %	63.5 %	17.9 %	65.1 %
	All	1123	100.0 %	43.9 %	57.2 %	24.4 %	57.6 %
SEM111	On-c	611	58.3 %	36.2 %	64.6 %	15.1 %	45.8 %
	Off-c	438	41.7 %	58.9 %	65.5 %	20.6 %	67.4 %
	All	1049	100.0 %	45.7 %	64.8 %	16.8 %	54.8 %
SEM212	On-c	190	50.7 %	16.8 %	61.3 %	14.6 %	29.0 %
	Off-c	185	49.3 %	26.0 %	66.5 %	9.5 %	33.0 %
	All	375	100.0 %	21.3 %	63.7 %	12.2 %	30.9 %
SEP101	On-c	812	69.4 %	20.9 %	57.7 %	25.9 %	41.4 %
	Off-c	358	30.6 %	47.5 %	67.1 %	20.2 %	58.1 %
	All	1170	100.0 %	29.1 %	59.8 %	24.6 %	46.5 %
All units combined	On-c	5922	64.1 %	27.6 %	58.7 %	21.5 %	43.1 %
	Off-c	3323	35.9 %	47.2 %	63.4 %	18.1 %	56.8 %
	All	9245	100.0 %	34.6 %	60.1 %	20.5 %	48.0 %

Table 2: Summary results for individual units and all units combined

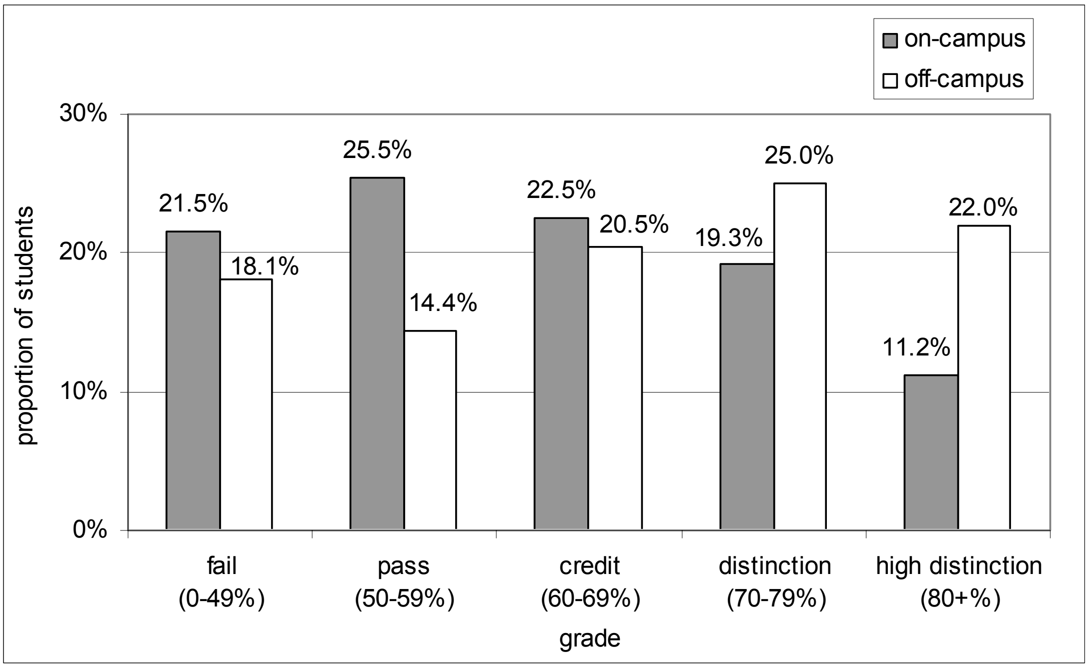

Figure 1: Distribution of final grades based on all data combined

Discussion

Overall

Combining all collected data, the following observations were made. Overall, the off-campus withdrawal rate was close to twice that for on-campus students, whether a student withdrew or not was highly correlated to mode of study ($\chi^2_5 = 541.528$, $p < 1 \times 10^{-114}$) and the rate of withdrawal was significantly different between the two student groups ($Z = -19.062$, $p = 0.000$). The grade distribution for completing students was significantly different between the two groups ($\chi^2_4 = 199.109$, $p < 1 \times 10^{-41}$) (see Figure 1) and the mean final grade was significantly higher for off-campus students ($F_1=66.684$, $p < 1 \times 10^{-15}$). The failure rate for off-campus students was significantly lower ($Z = -3.008$, $p < 0.003$), and the overall wastage rate was significantly higher for off-campus students ($Z = -12.570$, $p = 0.000$).

Persistence

In all except one (SEM212 in 1996) of the fifty cases investigated the off-campus withdrawal rate was found to be greater than the corresponding on-campus rate, and in a majority of cases the difference was statistically significant. After combining the five sets of data for each unit, only one unit (SEM212) out of ten had a withdrawal rate that wasn't significantly different between the two student groups – the enrolment in SEM212 was significantly less than other units, leading to less robust statistical inferences.

When withdrawal and failure rates were combined to yield wastage, there were only two units (SCM228 and SEM212) out of ten where the wastage rate wasn't significantly greater for off-campus students. It is interesting to note that SCM228 is a second year mathematics unit that follows on from SCM113 and SCM124, and SEM212 is a second year materials unit that follows on from SEM111. It could be suggested that students experiencing difficulty in these subject areas may have already withdrawn or failed at the first year level, leading to lower wastage rates at the second year level. The high wastage rate at the commencement of studies for off-campus students is noted in the literature (Glatter & Wedell, 1971). It is further noted that the only other second year level unit included in the study is SEB221, a second year engineering management unit that follows on from SEB121. Unlike SCM228 and SEM212, SEB221 did have a significantly higher wastage rate for off-campus students. But, many off-campus students are routinely exempted from SEB121 because of recognition of prior learning (RPL). So, for many off-campus students SEB221 will be the first unit in the engineering management studies stream that they encounter, and hence it may also have a higher wastage rate similar to many first year level units.

The overall wastage rate obtained by combining data from all units, for all years and both modes of study was 48.0 percent; this implies a persistence rate of 52.0 percent. This result is likely to be influenced both by the significant proportion of off-campus/mature age students in the survey group (who have high wastage rates) and the fact that the data is drawn from first and second year level units (which have high wastage rates). However, it is not markedly lower than the value of 55.8 percent reported in 1997 for all Australian engineering and surveying students who commenced their studies in 1992 (Urban et al., 1999).

Academic performance

After combining the five sets of data for each unit, the grade distributions of the two student groups were equally split; five were significantly different and five were not. While for the mean final grade four units were significantly different and six were not. As noted previously, when all data was combined, the overall grade distribution and mean final grade were significantly different, with off-campus students showing a mean final grade approximately 4.7 percent higher than on-campus students. In only two of the fifty cases investigated was the off-campus failure rate significantly different to the on-campus rate. Additionally, in both cases the off-campus failure rates were not markedly different from other years; the difference was that the corresponding on-campus failure rates were dramatically lower than other years.

General

Off-campus student success is affected by both internal and external factors. While some of these external factors are beyond the control of the university, there is much that the university can do to address internal factors within its control and reduce student wastage. University educational and administration systems are often designed around an idealized model of student preparation and circumstances. While a vision of an 'average' student may be a workable approximation for conventional entry on-campus students, the diversity of off-campus/mature age students requires more flexible university systems (Palmer, 2001a); there is a need to recognize the 'complex personal equations operating with individuals' (Woodley & Parlett, 1983) and design systems to accommodate them.

Conclusions

Based on a longitudinal study of 9245 unit enrolments in first and second year level units in the undergraduate engineering programs at the Deakin University School of Engineering and Technology, the conventional wisdom regarding the persistence and academic performance of off-campus students was confirmed. It was found that overall:

- the off-campus withdrawal rate was close to twice that for on-campus students;
- whether a student withdrew or not was highly correlated to mode of study;
- the rate of withdrawal was significantly different between the two student groups;
- the grade distribution for completing students was significantly different between the two groups;

- the mean final grade was significantly higher for off-campus students;
- the failure rate for off-campus students was significantly lower; and
- the overall wastage rate (withdrawn rate plus fail rate) was significantly higher for off-campus students.

Additionally, it was found that the year level of the unit influenced the off-campus wastage rate. Where the unit was the first in a study stream sequence to be encountered by off-campus students, the wastage rate was significantly higher than for on-campus students enrolled in the same unit. Where the unit was the second in a study stream sequence, there was no significant difference between on- and off-campus wastage rates.

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Factors impacting on the effectiveness of computer-assisted courseware

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***Abstract**: The level of satisfaction of computer-assisted tutorial courseware that is used as part of the undergraduate property and construction course at the University of Melbourne. It is important to determine if the computer-assisted teaching model improves the learning experience for students. This research examines the levels of satisfaction with a courseware model for teaching construction cost planning. The conclusions suggest that the advantages of the use of the model must be identified and actively supported throughout the whole course. In addition, further development of computer-based courseware is pointless unless the problems associated with their use can be minimized.*

***Keywords**: Construction education, computer-based teaching, cost planning*

Introduction

The objective of the paper is to evaluate the usefulness of a computer-assisted tutorial exercise. The paper discusses the educational theory surrounding the advantages and limitations of the computer based courseware as a learning model. In addition, the future directions of computer-assisted teaching models are explored.

The ultimate aim of the course is to produce graduates that can inter alia, become effective construction managers. However, there are a number of subsidiary objectives that can be articulated, these include;

- To engage the students as active learners
- To provide contextual information on real world concepts and examples
- Encourage the acquisition of the skills necessary to undertake construction projects
- To link principles with current construction practice

Teaching Environment

The University of Melbourne offers undergraduate courses in property and construction as a single undergraduate degree and also as course within a number of double undergraduate degrees including; architecture, commerce, geomatics-engineering and law. The subjects offered must accommodate several discrete cohorts of students that may have different perceptions of the value of the subject to their needs. In addition, class sizes are large, approximately 100 students, and site visits are difficult to organise, limiting the ability of students to obtain information about the context of the subject.

There are many educational difficulties in teaching undergraduates in construction. For example Kajewski (1999) suggested that large class sizes, tight timetables, busy site management, distant sites and site safety concerns have drastically curtailed such useful opportunities for a close up appreciation of construction processes.

This is impacting on the ability of modern undergraduates to understand the necessary contextual issues associated with cost planning. Many authors have stated that a contextual understanding of the problem is an important step in the learning process (Ramsden ,1988). However, teachers in construction management courses are increasingly having little success in providing students with an effective contextual experience in construction.

Background to computer-assisted teaching

Past research has shown that computer-assisted models can provide a worthwhile addition to the teaching aids used in the undergraduate subjects Menser (2001). For instance, computer courseware provides many advantages over traditional teaching approaches, including;

- Ability to undertake the exercise at times convenient to the student,
- Opportunity to repeat the exercise a number of times,
- Ability to interact with the computer model, and
- Capacity to be used by large class sizes.

Thus, computer assisted learning approaches have a much greater flexibility which may provide a better learning experience. However, computer based courseware is not without its own problems. Research by Oriogun (2001) showed that many aspects of the computer model are not well received by users. This had a very large impact on the ability of the courseware to deliver effective learning. Their results showed that 67% of the evaluators perceived the web based course provided by the University of North London was "unusable" for a variety of reasons, including:

- Ease and simplicity or use,
- Loading time, and
- Design concept

Menser (2001) also showed that many factors impacted on the courseware's effectiveness. Computer-based tutorials can only be used for the practice of low-level skills. Although there is some standard feedback dialogues, lecturers bring an insight into the way in which the student is approaching the problem. The face-to-face contact allows the personal intuition of the teacher to guide the student down the correct path. For instance the authors stated, "when students enter a wrong answer, it is usually wrong for good reason … students found that they need to talk to lecturers about questions arising from the computer-based problem." (Menser, 2000)

The use of computer-based tutorial exercises are best used as a supplement to an existing course, instead as a replacement for face-to-face teaching. Teaching needs enthusiasm and its effectiveness is dependent on creating that environment. "If the software is going to be used in places that are just intent on saving money, the lecturers have no interest in doing the teaching, the students (in turn) will sense the lack of enthusiasm, and just won't want to do it. " (Menser, 2001)

The term "useful" is defined as "producing or able to produce good results, and highly creditable or efficient" (Oxford , 1987). This implies that students believe that the computer-assisted model is worthwhile to the learning process. The model is designed to generate the following learning outcomes:

- Understand what an element represents.
- Know how to apply elemental cost planning techniques to a simple building.
- Understand the role of cost planning as a means of managing design costs.
- Appreciate some of the factors that impact on price.

Proposed Learning Model

Students are required to reach an understanding of the cost planning process and to develop some skill in the use of cost planning. A computer-assisted courseware tutorial exercise has been developed to enhance the learning process. The courseware is web based and has some degree of interactivity.

The objective of the exercise is to demonstrate how cost planning is achieved for a small building project. Students are required to prepare a detailed report on the cost of the building based on detailed information. Students are then required to reconcile the Elemental Cost Plan report with the cost of other similar buildings. Students are provided with detailed information on the building including some photos of the building under construction. Information provided, includes: floor plans, sections, elevations, details, specifications, and cost data. The task requires students to:

- Measure the Fully Enclosed Covered Area
- Measure the Unenclosed Covered Area
- Choose an Elemental Unit Rate from the cost data.
- Calculate the total building cost and percentage cost of each element
- Prepare a cost plan report

Research Instrument

The principle objective of the research was to determine the usefulness of the computer-assisted model for teaching cost planning. An expert on research design, Dr Som Naidu at the Multimedia Education Unit, University of Melbourne, assisted with the design of the research instrument. A number of instruments were examined, but in the end a questionnaire was chosen as the method most likely to achieve the best results.

There are many advantages of questionnaires, including; there is generally an absence of interviewing bias, and respondent is free from any pressure of being observed and possibly answer the questions more honestly. (Malhotra, 1993). This is particularly important because the students need to be sure that their responses do not form part of the assessment for the subject.

Care was taken with formation of questions to create a non biased survey to ensure respondents were not influenced in anyway. The general instructions provided with the questionnaire included an introduction to the questionnaire's purpose, assurance of confidentiality, and how and when to return the questionnaire. The questions were grouped into sections, to help structure the questionnaire and provide a flow, and both positive and negative items were intermingled to avoid leading the respondents.

Based on past research a survey was developed comprising four (4) questions that are used to evaluate courseware. It was assumed that approximately 10 minutes would be as much time as the respondents would be willing to devote to the whole exercise, including the brief introduction.

The final questionnaire was individually issued to each enrolled student during a tutorial session. The questionnaire contained three parts, (A) demographic information about the course enrolment of the respondent, (B) attitudes about the usefulness of the courseware and (C) comments. A copy of the questionnaire is included in the Appendix. The questionnaire was given to the 66 students enrolled in 702-361 Introduction to Cost Planning. There were a total of 60 that returned valid questionnaires giving a response rate of 91%.

Results

The results of the questionnaire are summarized in Table 1, and show that students generally found the courseware to be useful. All scores shown in Table 1 are above a score of two (2) out of three and therefore indicate that student's perceived that the courseware to be useful.

Courseware Attributes	Average Score (1 to 3)
Clarity of the task at hand	2.3
Ease of use	2.6
Simplicity of format	2.5
Visual appearance/design concept	2.5
User interface	2.4
System feedback	2.2
Ability to do in own time	2.8
Ability to repeat the exercise	2.6

Table 1: Student opinion on the "usefulness" of the computer-assisted tutorial exercise in meeting the "Learning Outcomes"

The results in Table 1 showed that the most well received attribute of the courseware was its ability to be done in the student's own time (2.8). Other attributes that also scored highly include Ease of use (2.6) and ability to repeat the exercise (2.6). The least useful aspect of the courseware was the ability to provide feedback (2.2).

Students enrolled in the subject were also probed about the difficulties that they experienced in using the courseware. The results in Tables 2 and 3 indicate their perceptions of the negative aspects of the computer-based learning exercise.

Courseware Attributes	Average Score (1 to 3)
Clarity of main page layout	2.3
Task page layout/design	2.4
Ease of use of Drawing page	2.2
Notes page layout/design	2.4
Ability to return to home page/navigation	2.3

Table 2: Student opinions on the difficulties experienced in using the computer-assisted tutorial model

The results in Table 2 show that all scores are over two (2) of three, which were labelled as good to excellent. In other words, in a similar way to the first set of questions, students did not generally have a negative attitude to using the courseware, and did not perceive that it performed poorly. Nevertheless, the least impressive characteristic of the tutorial program was the ease of use of the drawings page (2.2).

The next section of the questionnaire asked students to indicate the amount of time consumed in undertaking the exercise. The survey asked students whether they perceived the time taken was in a range from Short (1) to Too long (3). The results (Table 3) show that average scores were less than two (2) out of three, and therefore indicate that they believed that the courseware was not overly time-consuming. The courseware seemed to be working efficiently, and did not suffer from downloading problems.

Courseware Attributes	Average Score (1 to 3)
Loading time of exercise	1.7
Download of spreadsheet	1.5
Time taken to complete the spreadsheet	1.9
Time taken to answer the questions	1.9
Printing time	1.7

Table 3: Student perception of time consumed in undertaking the exercise.

The students were also asked to comment on the usefulness of the courseware, and many interesting responses were given. The comments were coded into two groups, those which were generally positive and those that were negative. In other words, comments that indicated that the tutorial exercise enhanced student learning was classed as positive for computer-based delivery, and those comments that were critical of some aspect of the experience were considered negative. Typical comments and anecdotes provided by students are included in Table 4.

Positive Comments	Negative Comments
The task was very clear and simple to do	The task was too easy and simplistic
The computer exercise could be done at any place and time.	Computer based exercise does not allow questions to be asked.
The assignment should allow for on-line submission	There were many discrepancies between the specification and the drawings
Written information is sometimes easier to understand for a non-English speaker than information presented verbally.	Drawings were not easily visible, dimension were difficult to read.
The computer exercise provided a practical application of the theoretical information taught in class.	The assignment took too long and should be worth more than the marks allocated

Table 4: Typical examples of supportive and critical comments

The results indicated that students were generally pleased with the effectiveness of the computer-based tutorial exercise. A number of positive and negative comments pointed out areas which need consideration in order to improve learning outcomes. The next section of the paper discussed the implication of the findings, and suggests what should happen in the future.

Discussions

One of the principal aims of this paper is to determine the effectiveness of computer-based courseware as an educational tool. The advantages of the using computer-based models must be identified and in addition, further development of courseware is unlikely to be useful unless the problems associated with their use can be minimized. As previously mentioned the evaluation of the usefulness of the courseware was determined by a questionnaire that was completed by enrolled students. The results of past research by Menser (2001) indicated that:

- Computer-based education is best used for the practice of low-level skills (Level of understanding),
- The face-to-face approach allows the personal intuition of the teacher to guide the student down the correct path (Face to face learning)
- Teaching needs enthusiasm and its effectiveness is dependent on creating that environment (Teacher commitment)

Level of Understanding

The results of the research indicate that students are, in general, satisfied that the computer-based exercise achieves what it set out to do. Students indicated (Table 1) that the exercise met the learning objectives set in advance, and therefore can be considered a successful learning experience. It may be reasonable to suggest that the learning objectives were not overly ambitious, but it has been argued by Menser (2001) that computer-based teaching tools do not deliver good results when there is a high level of understanding required.

The tasks given to students required them to measure and price a simple building, and this process had been demonstrated in advance during the lecture series. This aspect of the process seems to have worked successfully, the students indicated that it was useful for the exercise to be done in the student's own time and there was an ability to repeat the exercise a number of times.

Because the use of computer allows for repetition there may be some advantages for students with poor language skills. One comment suggested that "written information is sometimes easier to understand for a non-English speaker than information presented verbally"

It can be seen form the comments provided in the survey that many students enjoyed the learning experience. However, one student admitted that "The task was too easy and simplistic"; possibly the task was tedious for some. This indicates that computer-based learning models are best used to support other teaching modes. It is likely that an over use of these approaches can become long-winded and boring for many students who seek to be further enriched.

Face to face learning

Teacher-centred learning is particularly useful for situations where the delivery of theory is important. In this situation the lecturer can direct students along logical paths in order to reach certain rational outcomes. This approach allows students to engage with the lecturer.

The use of face-to-face lecturing has many advantages, one student stated “I don't get on with computers, they don't talk back, and you can't ask them questions”

The use of computer-based models is often less advantageous than “chalk-and-talk” styles when theory is being taught. This is because the student cannot engage with the computer freely, unless the computer-based solution is very highly structured. Respondents to the questionnaire were critical of the feedback that they got from the courseware, and it is likely that further development in this area would be useful. Instead, the computer exercise should provide a practical application of the theoretical information taught in class.

In addition, it is important to take special care that any documentation provided must not contain ambiguous information that may confuse the student. Frustration and confusion is likely to cause the student to disengage from the learning process, and this may lead to dissatisfaction. Another comment that added weight to this notion was that the screen size did not allow easy viewing of tutorial content, the student said, “drawings were not easily visible, and dimension were difficult to read”

Teacher commitment

The evaluation process has clearly demonstrated that the effectiveness of the computer-assisted courseware is partially dependant on the commitment of the teaching staff. Past research (Menser, 2001) indicated that good learning environments are those where a teacher is creating the correct educational environment.

The success of the courseware is conditional on the strategic use of software for learning exercises that maximize the effectiveness of the computer. It will not replace face-to-face learning, and is likely to fail if it is used in that manner. Its effectiveness is dependent on actively supporting teaching aims throughout the whole course.

Computer based teaching methods require a considerable amount of planning before commencement of the subject, and the time commitment is not insignificant. It is possible that time and resource limitations are one of the key issues facing the future development of courseware within universities.

Conclusions

The use of computer-assisted delivery of course material seems to be an appropriate and effective method for the students undertaking a course in construction cost planning. The results of the evaluation of the courseware proved positive, with most students indicating that the program had been a useful aid to understanding the material.

However, evaluation of the software showed that there were a number of limitations to the system. Many students commented on the inability of computer to provide timely feedback if further explanation is required. It is possible that if some students become frustrated with the use of the courseware, that they may ‘turn-off’ from further learning and disengage themselves from the experience. It has become obvious from the evaluations done is this research that the level of disengagement needs to monitored and steps should be taken to reduce it if appropriate. For instance it may be necessary to run further ‘face-to-face’ tutorial sessions to follow up any issues that occurred during the computer sessions. It is hoped that this may assist some students to realize the benefits of the courseware.

The next logical step would seem to be enhancement of the existing courseware. A number of opportunities emerged through the evaluation process, for examples: on-line help for common errors, better quality drawings possibly based on Computer Aided Drawing software, and limited use of email support.

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Further Developments in Multi-Media Immersive Teaching for Students of Manufacturing Systems

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Abstract: *This paper discusses the development of an immersive approach to teaching engineering students at the University of Auckland in the fields of Manufacturing Systems and Engineering Management. Project based learning initiatives in the Department of Mechanical Engineering have met with success and the Manufacturing Systems Group within the Department has continued with the development of its INFOstation virtual factory concept launched in 2001 and described by Seidel (2001). In 2002 and 2003 the concept has been expanded to include an immersive ergonomics project and a simulated capital equipment purchase exercise for students studying management accounting as part of a professional development course. This paper describes these initiatives, presents the results of student feedback on the ergonomics project and discusses what must be done to expand the INFOstation concept further in 2004.*

Keywords: *learning technologies, immersive learning, manufacturing systems*

The engineering degree at Auckland University

The University of Auckland offers a four-year Mechanical Engineering undergraduate degree. Year Three of the degree contains a compulsory course in Manufacturing Systems, which consists of an introduction to a broad range of manufacturing topics. The material covered ranges from product design and manufacture to industrial engineering techniques, ergonomics, automation principles, CAD/CAM, Robotics and factory/workstation planning. Students considering a career in manufacturing operations or manufacturing management will also take an elective Technology Management course in Year Four. This course reinforces their earlier year's work by requiring them to investigate, analyse and suggest solutions to real and current industrial manufacturing problems at local companies. With only two specialist manufacturing systems courses in the degree programme it is difficult to adequately expose students to what is considered to be core knowledge for manufacturing engineering and to ensure that students obtain as clear and cohesive a view of the topic area as possible. In particular it is difficult to emphasise and demonstrate to students the importance of systems integration and timeliness in the manufacturing sector as described by McCarthy (1996).

Project based learning

In order to give students an appreciation of actual manufacturing systems and processes and to maximise their workplace experience the Manufacturing Systems Group in the Department of Mechanical Engineering has for several years placed emphasis on a project based learning approach proposed by Tedford (1998). Year Four students (in groups of three or four) are, with the co-operation of local manufacturers, given actual industrial problems to investigate and solve. This programme has had encouraging results with positive student feedback and significant gains in conceptual learning. This is an effort to get away from assignments and laboratory experiments being carried out by just mechanically following given instructions. To successfully complete the course, students must demonstrate initiative, planning and teamwork and be prepared, if necessary, to carry out work and organise meetings outside what would normally be considered to be their `working hours'.

This emphasis on project-based learning whilst an improvement on solely lecture based education, cannot deal with all the problems associated with maximising manufacturing systems learning experiences for students. Although students discuss their allocated project with managers and others in the host company and learn about organisational structure, communication, note taking, etc., they are often not exposed to, or do not have time to explore, the full range of activities in the organisation and appreciate fully the complex interaction of job functions and processes in the plant. Generally speaking the complexities and interlocking operations of a typical manufacturing company are not fully experienced or understood.

As a means of extending the students manufacturing systems experience without utilising further visits to local companies, which are resource and time intensive, the Manufacturing Systems Group developed the INFOstation concept. INFOstation consists of a number of hypertext and multimedia based modules each of which covers a different aspect of manufacturing.

A brief description of INFOstation Limited

INFOstation Limited is a virtual manufacturing organisation that exists in the form of linked web pages on the Department's web server accessible to all students and whose initial concept was described by Seidel and Sitha (1999). The design scenario is that of a medium-sized manufacturing organisation with a virtual workforce of 200 spread across manufacturing, design and administrative functions. The INFOstation Limited homepage is shown in Figure 1.

Figure 1: The INFOstation Home Page

The ergonomics assignment

To trial the use of the virtual factory concept (as a replacement for local company visits to observe ergonomics issues in the workplace) an ergonomics assignment was delivered to the students using INFOstation Limited in 2001. This project was designed to make students aware of ergonomic issues, to reinforce the material on ergonomics covered in lectures, give students further practice in getting to grips quickly with professional engineering software (ErgoEASE®) and to practice the important skills of professional communication and report writing. In 2002 the assignment was refined and adapted as a result of student feedback. The refinements included modifying the multimedia interface to improve speed and realism and being more explicit as to what data was required in the students' final report.

To commence the assignment, students log onto the INFOstation Home page. Anyone may access the INFOstation web site, however, access to the ergonomics software is limited by the IS supervisor to students enrolled on the Manufacturing Systems course. Once logged in students are instructed that the company's ‘Planning Office’ is responsible for the efficient planning, maintenance and review of the handling, assembly and machining tasks within the organisation.

This responsibility includes ensuring that the staff are not required to carry out tasks that may be dangerous, excessively tiring, or detrimental to their health.

To make the assignment replicate a typical workplace project as closely as possible the students were asked to review an e-mail from the Manufacturing Manager at INFOstation asking them to immediately complete an ergonomic investigation into a handling operation that was causing concern. The e-mailed memorandum from the INFOstation Manufacturing Manager is reproduced below.

"Please complete an ergonomic investigation into our can unstacking operation.
Analyse the work cycle (shown in the video clip) including the initial and final reaching and lifting operations. Utilise Anthropometric Tables to estimate values/dimensions not given.
I would like you to write a detailed narrative of the video clip. Then enter the Handling and Motion sub-elements into our ErgoEASE® program from your narrative and carry out an ergonomic analysis.
In your report to me I would like you to:
a). Calculate the Maximum Kilo Calorie Rate/Minute (from your ErgoEASE® results).
b). Comment on the ergonomic relevance of the particular lifting cycle you have analysed in the context of the total task of unloading the pallet.
c). Complete a Rapid Upper Limb Assessment (RULA) analysis on what you regard as the two most ergonomically sensitive parts of the cycle.
d). Recommend a suitable illumination level for the workspace".

Having received the e-mailed instructions outlining what was required in their report and some basic workstation parameters, students clicking on a videocassette icon viewed a video clip of the operation (Figure 2) and some data collected by an earlier employee investigator. This data included the length of a worker's shift, the body weight of the operator concerned and the weight of the load being handled.

Figure 2: A still from the ergonomics video

The handling operation consisted of an operator removing bundled packs of 30 cans from a pallet, transporting them to a conveyor bench, unbundling the cans and pushing them onto a conveyor. The pallets were stacked six high forcing the operator into overhead reaches and, at the bottom of the stack, a severe crouching position. The operation also involved an extended horizontal reach to grasp the bundles in the middle of a pallet. The students could replay the video as often as they required and were able to step through the video in single frames in order to analyse accurately the various motion elements involved. A professional software package called ErgoEASE® was used to perform the ergonomic analysis. This program accepts input of each of the motion elements in the task (stepping, grasping, pulling, lifting, etc.) and produces a report on the ergonomic safety of the operation, amount of energy expended, etc.

It was suggested to students that as competent INFOstation employees their solution should consider all the usual, relevant industrial issues and constraints, e.g. costings, effectiveness of solution, payback period, downtime, likelihood of staff/union acceptance, etc.

Student response to the INFOstation ergonomics assignment

Following completion of the ergonomics assignment in 2002 students were surveyed to discover what they felt about the use of the INFOstation immersive scenario and whether or not they felt that it was an improvement to more conventional delivery systems. The survey instrument was developed in conjunction with the University's Centre for Professional Development and consisted of eight questions. Four of the questions were concerned with the design of the INFOstation interface whilst the additional questions (See Figure 3) dealt more broadly with the virtual factory concept and whether or not it should be extended to assist in the delivery of other topics. Students were asked to indicate their opinion on a five-point scale from "strongly agree" through to "strongly disagree". The survey was designed to give staff a reasonable level of feedback on the INFOstation concept whilst at the same time being quick and easy for the students to complete.

The results from this survey were encouraging. There was a substantial majority of students who agreed, or strongly agreed, that the INFOstation scenario had added interest and relevance to the project and indicated that they would like to see the concept extended. In future surveys it would be of interest to investigate to what extent, if any, a student's learning style preferences and personality type pre-dispose him or her to support this method of presentation.

The following Figure 3 lists the four 'broad issue' questions asked together with the student's responses.

Question	Strongly Agree (%)	Agree (%)	Undecided (%)	Disagree (%)	Strongly Disagree (%)
I had, or could obtain, all the resources I needed to complete the project	10	52	24	6	8
The use of a real industry scenario added interest to the project	20	48	24	2	6
The use of an industry scenario added relevancy to the project	12	54	22	10	2
I would recommend that the concept of industry based scenarios be extended to other Manufacturing Systems topics	14	64	20	2	0

Figure 3: Table of survey results

It can be seen from the table above that 24% of students were undecided about whether or not they had, or could obtain, all the resources needed to complete the project. The next survey of this course will attempt to elicit more information about students' attitudes/concerns in this area.

Discussions with students during the course of the assignment and at its completion were positive. Students felt pleased that they had met the challenge of quickly learning and producing results from a new software suite in an area new to them. Many comments were received about the use of the video clip of a real workplace manual task and students expressed empathy/sympathy with the hard-working operator in the video and although they had never met her several students remarked that at the end of the exercise they felt they knew her well.

Latest developments

Encouraged by the success of the ergonomics project the INFOstation concept will be expanded in the first semester of 2003 by opening further pages on the INFOstation web site describing the activities of INFOstation 's administration and accounting functions. To involve the students in this part of the organisation's activities it needed to be introduced during the Year Three Professional Development course which is dedicated to studying 'Engineering Management' tools and strategies. The new INFOstation activity is focussed on the topic of Management Accounting, a substantial proportion of the course (33%).

Management accounting assignment

The previous management accounting teaching material consisted of a series of notes on issues such as balance sheets (financial statements), rate of return, opportunity costs etc. with the notes being supplemented with a number of worked examples. The examples, however, were a mixed bag of imaginary organisations from "Sid's Barbershop" through to the "All-Day Candy Company". This disparate collection is now being replaced by examples more closely related to engineering and with INFOstation Limited as the common theme.

The management accounting assignment that students must complete in this Professional Development course has also been redesigned to make use of the INFOstation Limited concept. The manufacturing manager of INFOstation presents the students with the problem of a lower than expected throughput of a manufacturing process. Students are required to analyse their options for improvement including the selection and purchase of one or more computerised automated assembly machines. Students must compare the capital costs, installation and maintenance expenses and expected payback period of each alternative. They must allow for the costs of borrowing, depreciation and expected return on investment. The assignment is designed to give students practice in applying what they have learnt during the management accounting lectures and an appreciation of the decisions that must be made when a company is considering reinvestment in plant. It is also designed to equip them with the tools to adequately argue a financial case to colleagues and managers.

The participants in this course, as engineering students, are not always convinced about the relevance of management accounting to their chosen profession. It is hoped that the INFOstation context within which this topic is delivered and the consistent theme will help to demonstrate to students the relevance and importance of this area to practising engineers. Almost all graduates of course will at one time or another share responsibility for earning, allocating, and spending their organisations liquid assets.

Design Projects

In addition to the delivery of the ergonomics and management accounting material described above, the INFOstation concept has been used in 2002 and 2003 to deliver design problems to Year One and Year Three students in a design course in as immersive a fashion as possible at this stage of development.

Design projects are based around a customer inquiry presented to the students in a letter by the General Manager of INFOstation Limited. The letter is addressed to 'Engineering Design Consultants', a fictitious commercial design consultancy consisting of the different project groups established in the class. The project task is based on a relatively vaguely defined design problem that the project groups first have to process systematically through the needs assessment phase into a formal product design specification. In the next project phase they have to apply a structured approach and a number of creative techniques and decision making tools to create a range of concept ideas, select one of these alternatives and then to develop this into a comprehensive conceptual design proposal which they present as a written design report.

Further development

Our experience with the benefits of the INFOstation concept have encouraged us to continue with its development and refinement. At this stage it seems near to reaching its full potential as a vehicle for the delivery of immersive student assignments and projects. If it is to be truly a virtual factory around which the teaching of manufacturing systems at the University is to revolve, it will now need to be incorporated fully into relevant lecturing and tutorial materials used in the department. In particular it is envisaged to create a link between the virtual INFOstation environment and the manufacturing hardware facilities in the Department's laboratories.

Currently the laboratory for the Manufacturing Systems Research Group includes an industrial KUKA robot (payload 15kg) and a smaller Eshed robot (payload 1kg), a computer numerically controlled lathe, a milling machine, conveyor system and a number of pneumatic control tool kits. The laboratory also has a number of software tools including Pro/Engineer for computer aided design, manufacturing and engineering; Quest a manufacturing simulation tool; EASE for industrial engineering optimisation and ErgoEASE, an ergonomic analysis tool.

Currently the Cell is used to assist students with investigations into robotic programming, robotic assembly and CNC programming. The planned link between the INFOstation and the cell will give students some exposure to workplace integration problems, procedures and software. The union of the existing hardware and software tools with INFOstation will enable us to expand INFOstation into the simulation of manufacturing system functions such as statistical quality control methods, cycle time analysis, material and machine hour costings, reliability analysis and scheduling issues. All of these functions have the capability of expanding and enriching the immersive experience for students. In future developments it is possible that a live connection could be made via the Internet with a local manufacturer as suggested by Dessouky and Verma (2001).

When these steps have been taken INFOstation's useful new function would be to act as an integrating agent to assist staff to demonstrate the holistic nature of engineering activities. Industry now recognises the fact that marketing, quality, engineering, manufacturing and production can no longer operate independently and has created new approaches to product design and manufacturing such as concurrent engineering and integrated product development. INFOstation's next evolution will be to demonstrate the reality of integration and act as the common link in teaching product design, design for production and assembly, materials and process selection, and assessment of a product's financial viability.

This next step in the evolution of INFOstation will require its developers to win the 'hearts and minds' of their colleagues to assure them that the time and energy they will need to expend to incorporate the INFOstation concept into their exiting teaching practices and material will pay handsome dividends. Rather than being a drawback the authors of this paper believe that this challenge will help to refine and optimise the concept and help them to ensure that each incremental concept development is backed up by demonstrable pedagogical benefits along with approval from students.

Conclusions

The staff involved in the INFOstation project and its application to the teaching of design and ergonomics issues to engineering students believe that the exercises were successful and this is strongly borne out by the results of the survey carried out after the completion of the ergonomics assignment. By delivering the topic in a more immersive fashion, students felt that it was more "realistic" and more interesting than "run of the mill" assignments. The returned assignments were generally of a high quality with some students really getting into the spirit of the exercise and presenting their results and commentary in the format, style and language they would be expected to use in a workplace memorandum and technical report. Students learnt a great deal about extracting data and instructions from a wordy memorandum. A survey will be carried out at the completion of the Professional Development course to see if these benefits were also observed by the students involved in the management accounting assignment.

The next and perhaps most challenging step, is to introduce an immersive and consistent virtual factory scenario to general teaching and tutorial material. This will require the co-operation of a wider range of teaching staff than have been involved to date and require those involved in the ongoing development of the INFOstation project to be thorough in their development plans and pedagogical justification for its use.

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Does the Supply of Lecturer's Overheads to the Students Make a Difference? - A Water Engineering Case Study

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Abstract: *While the advent of modern computer and communication systems has opened up a plethora of methods for supplying students with teaching support material, a major question remains as to what is effective for student learning? This paper presents the outcome of a six-year case study on the effectiveness of supplying students with the lecturer's actual presentation notes (overheads) as a learning aid. Results showed that direct access to the notes did not appear to enhance student learning, suggesting that the lecturer's effort should be placed elsewhere when designing and supplying support material.*

Keywords: *lecture notes, teaching strategies, evaluation.*

Introduction

With the advent of faster and more accessible electronic communication methods, the tertiary educator now has a wide range of methods for supplying students with educationally significant support material. Computer simulations and aided learning packages (eg Dharmappa, Corderoy, and Hagare, 2000, Parkinson and Hudson, 2002, Wilbon, 2003), on-line chat groups and discussion forums and electronic print material (eg pdf files and Internet sites) are now supplementing the more historical forms such as books, papers, videos and audio recordings (eg Lemckert, Martin and Wong, 1995, Brostow, 2001). The success of this material as an effective teaching aid has come under increasing scrutiny as we endeavour to enhance student learning. Of course, it is also important to note the significance of other forms of non-electronic based educational strategies such as industry placement programs (eg Edwards, 1997, Dunai, Hufnágl and Iványi, 1998, Lyshevski, 2002).

As it is the lecturer's task to design and facilitate the learning process, it is they who determine the use of the abovementioned learning support systems. Certainly they should engage students in active relevant learning processes and encourage deep learning activities (eg Biggs and Moore, 1984 and Wilbon, 2003). However, the student cohort can also be involved in selection of the material in either a formal or informal manner. For example, with problem/project-based learning approaches the students can decide upon what material they find most informative and beneficial to their assigned educational task. In some instances self-driven site visits and interviews may be of significant use in the learning process.

This paper presents a case study undertaken during the teaching of a final year engineering course. The study, spanning six (6) years, offers a unique example of assessing the importance the supply of lecturer's notes (overheads) has on student learning outcomes. The paper will first describe the case study and then comment on the outcomes. Results of this study showed that the form of material (if any was supplied) appeared to make little difference to student learning and that this form of educational material should not receive greater attention.

The Case Study

This paper uses data collected from the Water and Wastewater Engineering course, a 4th year core course offered within the Bachelor of Civil Engineering Degree at Griffith University (Gold Coast Campus). The subject aimed to introduce civil engineering students to key concepts relating to civil engineering components (including environmental and fluid mechanic processes) within water and wastewater treatment plants.

Subject Structure

The course was divided into two equal-sized sequential modules of 7 weeks' duration. The first module was presented in the 'traditional' manner, using formal lectures of three (3) hours per week and tutorial classes of one (1) hour per week, with the teaching emphasis being placed upon development of the understanding of theory and concepts relating to water treatment plant design. The lecture component predominantly considered the introduction of new concepts and theories, while the tutorials were primarily aimed at numerical-based problems.

The second module on wastewater treatment plant design was presented as a problem/project-based learning exercise, with no formal classes. In this module, the students were divided into small groups and asked to design the basic structure of a wastewater treatment plant. That is, they were asked to solve a real-life problem which could only be achieved by their seeking knowledge and learning about wastewater treatment plant processes. Informal contact sessions were regularly scheduled to allow students the opportunity to seek assistance with the recommended reading, the problem-solving list and the design project.

Throughout the duration of the course (from 1997 to 2002) the same lecturer delivered the lectures, with the tutorials either being undertaken by the lecturer himself or by professional tutoring staff. Typically, students were supplied with the lecturer's presentation notes (overheads), which were usually in the form of overhead transparency slides (a common and virtually standard practice within Griffith University). As a consequence of technology innovations and an effort by the lecturer to enhance student learning, the method by which students could access the material varied (see Table 1). Table 1 shows that the range of the method of supply extended from full electronic access to nothing. In 1999 no overhead material was available to the students outside the lectures; this meant the students had to write down all the material if they were prepared to do so (this approach goes back to the pre 90's when students had to write everything down). While this method may seem archaic and is maligned (supposedly because it prevents students from listening openly to the lecturer) it was trialled in order to address an issue raised from the 1997 and 1998 period. In 1997 and 1998 the students had access to the material but they seemed hesitant to make any additional notes during lectures, relying instead on the printed matter only as a learning aid. Feedback obtained from the students revealed they did not feel the need to write anything down as they already had it, which could result in poor knowledge development and retention. After 1999 material was supplied at different levels of content and accessibility. In 2002 all material used in lecture presentations was supplied to the students. This required significant effort by the lecturer to ensure all the material was in a suitable format and professionally presented (ie. not hand written). The question examined here is "*Does the Supply of Lecturers' Overheads to the Students Make a Difference?*"

Year	Delivery Method
1997	Available from University library computer system. File printable only.
1998	Available from University library computer system. File printable only.
1999	Non handed out or made available
2000	Limited printed notes were handed out with only overhead summaries given.
2001	Limited printed notes were handed out with only overhead summaries given. Links to WWW sites relevant to the course were also supplied
2002	Full access to all material via student computer access system.

Table 1: Water and Wastewater Engineering Module 1 lecturer's notes delivery method

Student Performance Evaluation Process

The primary aim of this study was to consider the performance of the students following the completion of Module One over each of the six years from 1997 to 2002, inclusive. For the outcomes of Module Two, albeit over a shorter period, the reader is referred to Lemckert (1999).

At the completion of Module One each student was required to complete a formal examination (in addition to another at the end of the course). Like many traditional examinations, this one-hour exercise was designed to assess the student's overall understanding of the course material. In this case, it examined their understanding of the application of theory and concepts of the civil engineering design components used in water treatment plants. The examination paper consisted of three (3) questions with numerical and theoretical components. For completeness, a copy of the examination questions is presented in Table 2. Students were supplied with a formula sheet for use in the examination. The total weighting of the examination paper (in terms of overall course grade) was not high, and set to 10 %. All answers relating to the questions were addressed in lectures and/or tutorials.

The same examination paper was used in all years of the case study (students were not informed of this), thus permitting direct comparison between years. The examination was conducted 'in-house' and students were not permitted to remove the examination paper from the examination room, meaning no copies of the paper were available for students to keep and pass on to students in lower years. Indeed, it appeared that the students did not even pass on the details of the examination paper on a verbal level.

Student Performance Comparison and Discussion

While examinations are not the sole means of assessing student performance (and they certainly should not be) they are commonly utilised performance evaluation mechanisms. Figure 1 summarises the students' performance over the six (6) years of the case study. Here the average mark (plus or minus one standard deviation) from each year has been plotted.

Question Number	Question
1	a) List the four basic types of water quality groupings b) Define BOD_5 c) The BOD of a wastewater stream is determined to be 150 mg/l at 20ºC. The k_{20} value is known to be 0.23 per day. What would be the BOD_8 if the test was run at 18ºC ?
2	a) What is the primary function of screening ? b) Describe two methods by which grit chambers can be designed to have a constant through flow rate (sketches may be used). c) List the two main methods by which aeration can be achieved
3	a) What is meant by the two terms perikinetic and orthokinetic. b) List and describe the three steps of coagulation process and describe their purposes.

Table 2. Water and Wastewater Engineering Module 1 examination paper.

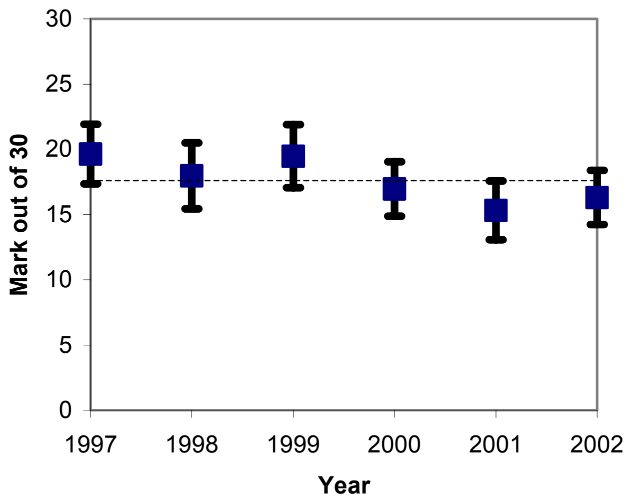

Figure 1: Plot of average module one examination mark against year. The graph also shows the level of one standard deviation from the mean. The dashed line indicates that there is no significant difference in the grades.

Initial observation of Figure 1 suggests that student performance changes from year to year. However, within one standard deviation there is no significant difference between results, suggesting that the type and delivery of the student support material may have minimal influence on student performance (when evaluated using formal examinations).

The result observed in Figure 1 warrants further examination and comment. The teaching of this course was conducted in a similar manner, from year to year, with the major difference in style being the method of supply of the lecturer's notes (overheads) to the student (see Table 1). In 1999 the notes were not directly to students, while in 2000 only complex formulae were supplied (ie no overhead copies) in order to minimise mistakes during the copying down process. In response to colleagues' suggestions and student feedback in 2002 the lecturer took significant effort and time to once again supply students with all of the lecturer's course notes. All material had to be made accessible through a Griffith University electronic delivery system (known as Learning@GU), which is assessable to all enrolled students.

Brostow (2001) supports a well-known observation in discussing how students will be expected to perform differently from one year to another, depending on the makeup of the student cohort. The variation in the mean grade observed in this case study might therefore be the result of the student or more importantly learning style only. Unfortunately, from this essentially limited investigation (even though it lasted 6 years) it is not possible to completely determine the cause in the mean grade differences. Whatever the reason, it appears it was not necessary to supply any material at all to the students in order to observe significant improvement in student performance. Therefore, it is recommended the lecturer should concentrate more on other methods to enhance student learning.

Conclusions

A case study was undertaken to evaluate how the supply of a lecturer's lecturing notes influenced the level of student learning. While students expect to be supplied with such material as a matter of course it is apparent that it does not impact significantly on their degree of learning, as assessed by formal examination. This outcome suggests the lecturer should not place undue effort on developing their own notes, with the intention of improving student learning, focusing instead upon developing adequate notes and improving student learning through alternate means. Therefore, in answer to the question "*Does the Supply of Lecturers' Overheads to the Students Make a Difference?*" it would appear that the answer is *NO*, but more study is required.

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Acknowledgements

The author would like to thank the School of Engineering for supporting educational research and development activities.

An electronic tutor for mechanical engineering

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***Abstract**: For a variety of safety and economic reasons, engineering undergraduates in Australia have experienced diminishing access to the real hardware that is typically the embodiment of their theoretical studies. This trend will delay the development of practical competence, decrease the ability to model and design, and suppress motivation in all but the most imaginative students. The authors have attempted to address this concern by creating a software tool that contains both photographic images of real machinery, and sets of modelling 'tools'. Academics can use the software to set tutorial tasks, and incorporate feedback comments for a range of student responses. An evaluation of the software demonstrated that students who had solved modelling problems with the aid of the electronic tutor performed significantly better in formal examinations with similar modelling tasks.*

***Keywords**: Modelling, structural distillation, CAL, tutoring*

Introduction

Among the multitude of difficulties facing 21st century engineering education are two that are growing more critical as time progresses: (a) pressures of reduced government funding have increased student/staff ratios and reduced opportunities for personalised tutoring, and (b) those reductions in funding, along with increased concerns about liability and safety have limited the opportunities for hands-on or otherwise realistic experiences for undergraduate engineers. When coupled with the shift toward student-centred learning (and the desire to match learning opportunities to individual needs) we find that those difficulties lead to students' perceptions of a widening gulf between engineering practice and engineering education, with increasingly scarce opportunities for connecting individuals with their future profession.

Those funding reductions are being addressed (to varying degrees of success) by a need for universities to earn income from other activities – mainly through research grants. Research success is consequently a desirable attribute for modern academics, while ongoing liaisons within the profession are less well regarded. Time, modest practical experience and funding limitations also create a gulf between many engineers in academia and industry, and this has an impact on the programs of teaching offered in engineering courses.

The authors have observed that the majority of engineering sciences taught at their universities are bereft of the artefacts associated with the science, and in some instances, are bereft of realistic representations (e.g., photographs, videoclips) of those artefacts. Yet we have observed that students are highly motivated by the existence of realistic ("practical") examples of the theory: it appears that an appreciation of abstractions requires some time to mature, perhaps even well after graduation for some. The experienced teacher-researcher already possesses this ability to abstract from reality, and often teaches from the abstraction, rather from the reality. This approach can lead to student dissatisfaction and their evaluation comments that a study unit is "too theoretical".

The act of constructing an abstraction from reality is called modelling. Models may be mathematical/algebraic, physical, graphical or symbolic, or some combinations of these. When the models contain elements that are the basic building blocks of the engineering discipline, we call the modelling process that of 'structural distillation' (Samuel and Weir, 1999). The usual step following such a structural distillation is to find and include the numerical data that is specific to the discipline, thereby allowing the engineer to make specific predictions from the model.

It is evident that a practicing engineer should be able to form proper and correct models, uncover the data for their particular problem, and then 'solve' the problem to meet the final need (Samuel and Weir, 1991). Yet there is little evidence that undergraduate engineers are schooled in the art of structural. The gap in this ability became apparent to the authors, whose specialist teaching area is in mechanical design. In open-ended design problems the student may progress in either of two directions: (a) from a concept toward determining if that concept will work, or (b) from a calculated (numerical/graphical) descriptor of the requirements toward the physical embodiment that would achieve the requirements. In both instances the student needs to formulate a model that bridges the two elements, and this is often the most inadequately-performed task in an undergraduate design (Ferguson, 1992).

Most of the conceptual modelling tasks (structural distillations) needed in undergraduate problems are very basic, and require only a few minutes of effort (from a capable student). It is impractical to personally tutor large groups of students in this undertaking. With this restriction in mind, coupled with the concern for the reduction in 'practicality' in many undergraduate engineering courses, the authors conceived the potential for a computer-based tutor that could: (a) contain realistic representations of engineering artefacts (perhaps animated), (b) offer a method of allowing students to formulate structural distillations of those artefacts, and (c) impement a technique for correcting errors on an individualised basis.

Support for the development of such software was forthcoming in 2001 from a joint funding scheme created by the authors' universities. The basic version of the electronic tutor was written during that year, and is called MOMUS Tutor (Monash-Melbourne Universities' Structural Tutor). (Momus is also a word for a fault-finder, or persistent critic, derived from the Greek god of ridicule.)

This paper describes the underlying educational philosophies and program structure of the MOMUS Tutor, and reports the educational outcomes from its first year of use.

Principles of MOMUS Tutor

It was intended that the proposed electronic tutor should be available for structural distillations in any of the engineering sciences in a mechanical engineering course, and it was envisaged that, since the fundamental issues being addressed by the tutor were likely to be common across several disciplines (and outside of engineering), it might be possible to construct a fairly general tool. Since the engineering sciences tend to work in relative isolation, and students see this separation in their timetables, it was desirable to compartmentalise the modelling activities for each science. It was also recognised that the issues of modelling within one sub-discipline need to be tested over several different circumstances to ensure that the principles have been properly learned. These aspects led the authors to believe that it should be possible to construct a tutoring program with generalised capabilities, that could be customised for separate artefacts, sciences, and disciplines.

The requirements suggested a 'grid' of tutorial tasks, with artefacts and sciences forming the two axes, and one or more tasks made available in each of the grid elements. Figure 1 is the problem grid for MOMUS Tutor (February 2003 version). The intention was that problems could be generated in each of the grid elements, and students might select individual problems, sets of problems from an engineering science (a column), or the issues associated with an artefact (a row). The authors were especially interested in the formulation of problems along a row, since this should illustrate the integration of several engineering sciences within the design of an artefact (one of the primary purposes of an engineering design unit).

The artefacts themselves were intended to be realistic representations, so were likely to be information-rich (such as photographs, videotape, or rendered 3-D models), causing the artefact representations to occupy large volumes of electronic memory. To minimise the difficulty in manipulating such large amounts of memory, it was also desirable that the artefacts be suitable for modelling tasks in several sciences. At present, it is expected that the final version of the MOMUS Tutor with eight different machines will fit onto a conventional CD ROM, or be available through campus networks, although it may not be suitable for dial-in modem access.

MOMUS Tutor was coded in Macromedia's Director, a common base for educational software. It allows for the simple creation of a stand-alone 'projector' for distribution, and compressed versions to be played by Shockwave (free downloadable software from Macromedia). Figure 1 shows the basic program structure. The starting 'movie' allows students to jump to an introduction, describing the purpose of the software and how to use it, or go directly to the problem movie. From the contents frame (Figure 2) one or more problems can be selected, then attempted in sequence. The hardware is represented in separate 'frames' of the movie, and the separate sciences are represented by independent 'casts' (Rosenzweig, 2000) of icons.

A problem is constructed from the combination of an artefact with the contents of a science cast, plus the specific text that is authored for each problem.

The potential to animate machines (in order to gain insight into their functionality) and the need to isolate portions of a machine in some modelling processes led to the decision to 'construct' the artefacts from separate images, 'assembled' together to show the whole machine. Figure 3 is the screen image of the first problem in the grid shown in Figure 2.

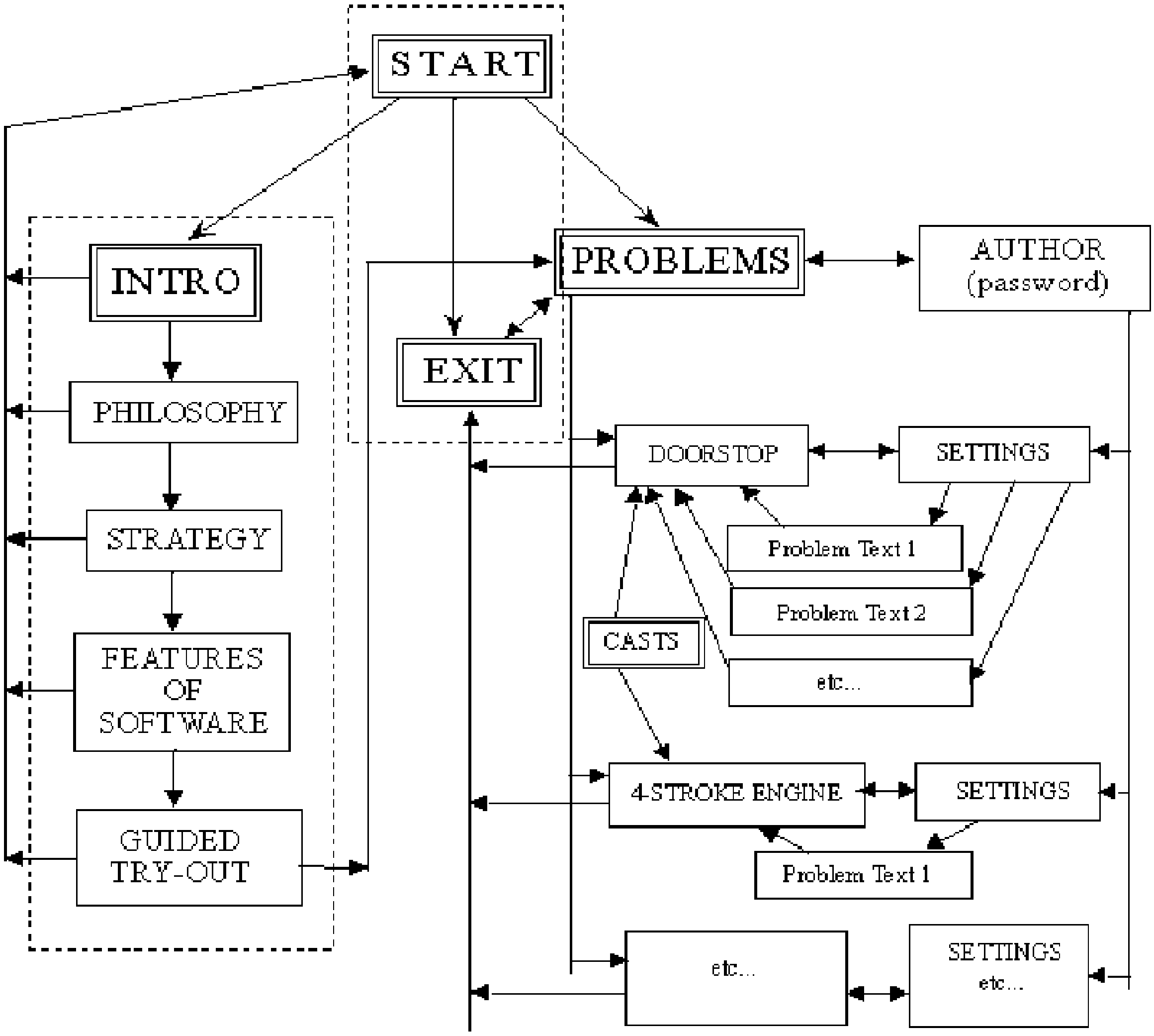

Figure 1: Structure of the MOMUS Tutor

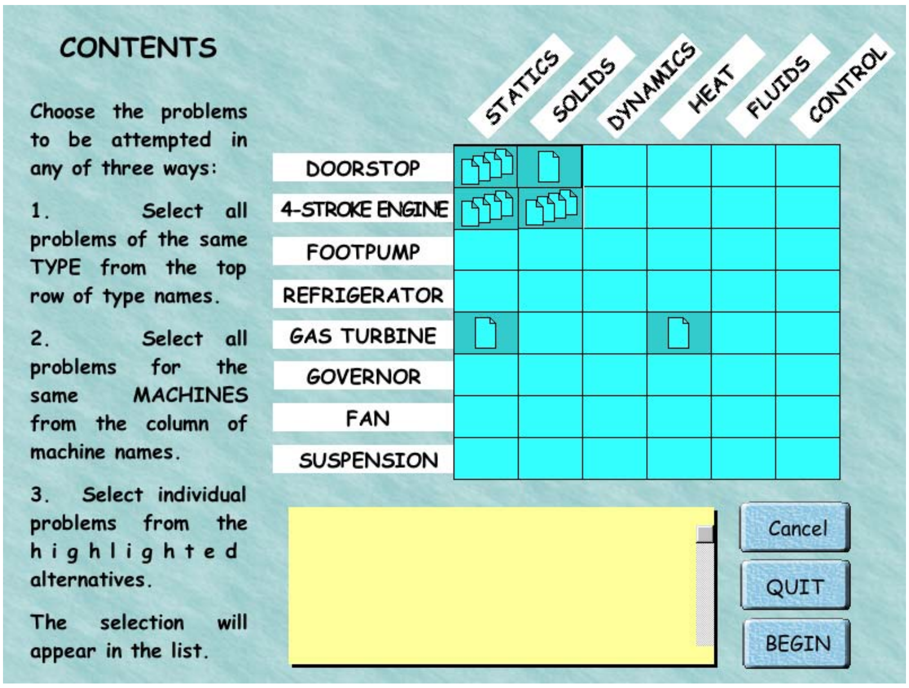

Figure 2: Contents page of MOMUS Tutor with several problems available

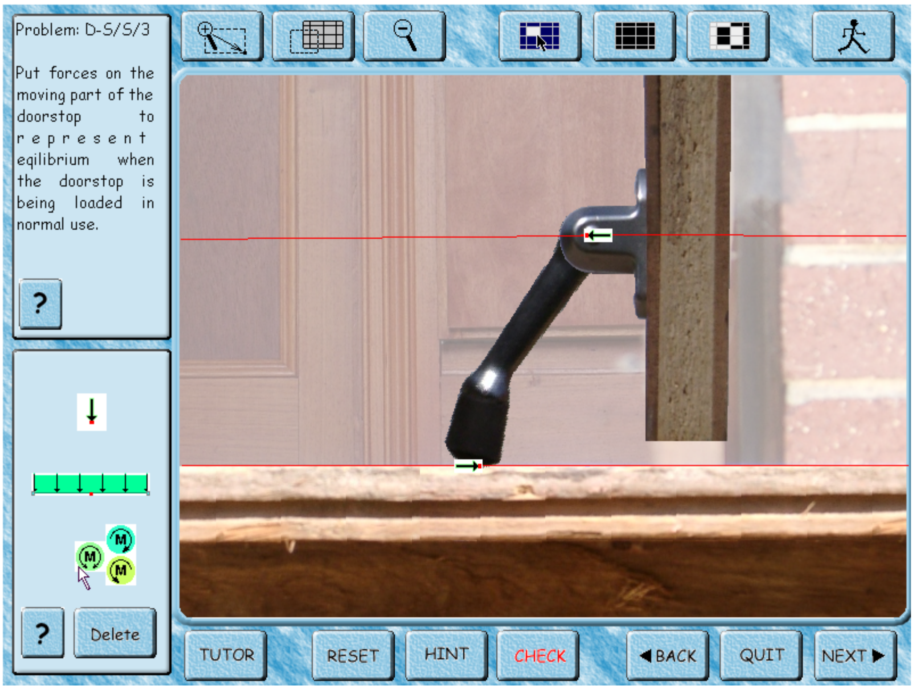

Figure 3: Appearance of MOMUS Tutor screen during an attempt to solve a problem

Through the top row of buttons the student has access to tools that allow the machine to be ‘operated’ (animated or re-configured), and parts to be ‘selected’ (highlighted) or made transparent so that the inner workings can be observed. Other buttons allow the user to zoom in or out so that small assemblages, or the whole machine in its context, can be viewed. Students are able to construct the line-diagram models that represent the machine or selected portion of the machine by dragging and dropping segments of the model onto the appropriate part of the image(s). A typical tutorial problem would ask a student to construct a line diagram model for some part of the image under defined external conditions (e.g., loads, temperatures, speeds) that might be used in the solution within a particular engineering science (e.g., dynamics, thermodynamics, control). Their answer will comprise several components, including the machine configuration at some point in its cycle, the highlighted components, and the locations, shapes and alignments of the various modeling ‘icons’ that define the model. The answer is therefore essentially a unique 2-D image, the construction of which is rendered in a convenient manner by the Tutor’s interface.

Figure 3 shows the screen of the Tutor during the formulation of an answer to a basic problem in statics. The object (in this case a simple doorstop) fills the main window. The task is defined in the upper left-hand window, and the modeling icons (point and distributed forces, and moments) are available in the lower left-hand window. When the Tutor offers feedback after a student asks it to ‘Check’ the answer, a feedback window overlays modeling icons. The top row of buttons allow the image to be manipulated – zoomed, selected and animated, and the lower row of buttons allow the problems to be navigated. The student’s answer (in the case shown in Figure 3) is two copies of the point force icon dragged, dropped and rotated onto the image, which now contains several de-selected parts of the machine, defining the free-body boundary.

The Tutor is programmed to diagnose the student’s answer, and then to offer appropriate comments that have been prepared in advance by the educator who set the problem after switching the software to an authoring mode.

While authoring, the educator has the opportunity to create a number of possible ‘solutions’ – correct or incorrect, that are judged to be likely responses by novice designers. The first solution that the educator creates is defined as the ‘target’ solution (the most desired correct solution), but any successive solutions loaded into the Tutor can be examples of the most common types of errors that students tend to make. For example, the solution shown in Figure 3 was an incorrect solution that was offered by 20% of the students who attempted the problem when it was set on paper as a ‘spot test’ during 2002! This approach follows a similar philosophy to that adopted by Scott and Stone (1998) with their introductory Dynamics tutor at the University of Western Australia and their generalised ‘Jellyfish’ tutorial environment. Using the set of authored ‘solutions’, the diagnosis in the MOMUS Tutor is performed in two stages.

First stage: The diagnosis conducted by the Tutor is a search through its set of stored solutions for a close match (within author-selectable tolerances), and, if it finds a match, the Tutor offers the corresponding feedback comment that was pre-stored along with that solution.

Second stage: If a close match to the student’s answer is not found, the Tutor uses it’s second diagnosis routine. In this routine the Tutor compares successive elements of the answer with the ‘target solution’, and offers feedback associated with the first substantial mismatch that it finds. These feedback comments were also pre-stored when the educator set the problem, and cover circumstances such as ‘incorrectly selected parts’, ‘inappropriate icons’, ‘missing icons’, and wrongly placed, sized and rotated icons.

The Tutor keeps track of the number of times that an identical ‘error’ occurs, and provides access to second and third level ‘hints’ that the educator has prepared. The student has no direct access to the ‘target’ solution, or any other ‘good’ solutions that have been stored, so the hints and feedback have to be constructed by the educator to direct students toward the target, and the target solution needs to have a feedback comment that identifies itself as the termination of the problem. In this way it was intended that the Tutor could follow a similar structured approach to that of an experienced human personal tutor.

Authoring in MOMUS Tutor

The access point for problems in the Tutor is a ‘contents page’. This page (Figure 2) displays a grid, where the rows represent the alternative ‘machines’ available for analysis. The ‘doorstop’ in Figure 3 is one of these machines. The columns represent the engineering sciences for which problems may be authored. The ‘static equilibrium’ icons in Figure 3 belong to one of the engineering sciences. It is therefore possible to set or access problems in any of the nominated engineering sciences applied to any of the machines, by selecting the corresponding grid element. The Tutor can be used to create, then access up to nine problems in each grid element, although it starts from a completely empty grid. Currently the grid is 8 machines x 6 sciences, allowing access for 8x6x9 = 432 separate problems.

After entering the authoring mode, protected by a password, the educator can select any of the grid elements to create or edit a problem. This route is shown down the right hand side of Figure 1. The starting configuration is then chosen: image size, scales, default sensitivities (tolerances) for the diagnosis, the problem text and the subset of modeling icons, including any pre-placed icons if desired. The feedback comments associated with the second stage diagnosis are then entered, followed by the target configuration and its specific comments. The required diagnostic accuracy (tolerance) for this, and other sample solutions can be set for each solution by manipulating visual 'tolerance zones'. For icons that can be rotated, the tolerance zones for the alignment are shown as sectors of a circle, such as those shown as dark pink associated with a 'beam' icon in Figure 4: the Tutor will accept any alignment of the icon that falls within the sector. The tolerance zones for positions of icons in x-y space are rectangular areas, such as those associated with the forces in Figure 4. Other icons may have special characteristics: the length of the beam in Figure 4 can be no less that that shown, but could be larger (with redundant overhang), so its tolerance zone for length is indefinitely long each side of a central minimum length.

Any number of alternative solutions and their feedback comments are then entered. The problem-setting task is then terminated, and all of the information about the problem and its solutions is recorded in a separate text file, averaging 35 kilobytes in size (and easily transmitted through the internet).

Subsequently, when the Tutor is opened, it searches its default directory for problem text files, and, finding any, makes them accessible in the contents page. In the authoring mode, any existing problem can be edited or extended: in the tutoring mode, each problem can be selected individually, or in sets, and attempted by students.

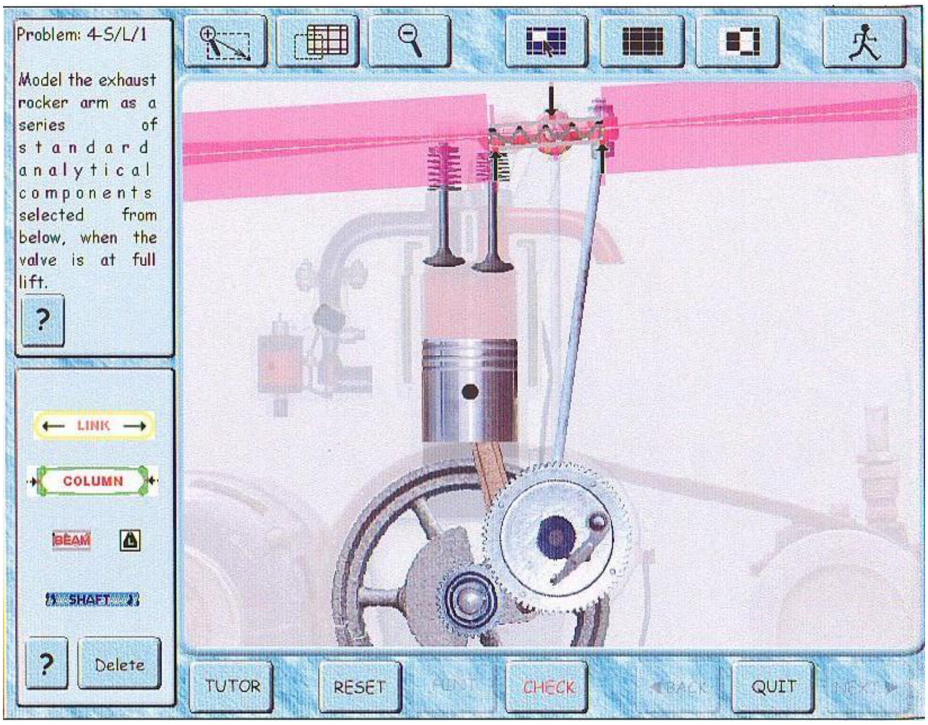

Figure 4: Authoring a problem, showing the pink tolerance zones associated with machine element icons (beam and point forces)

Evaluation of MOMUS Tutor

The development team completed the coding of the core parts of the MOMUS Tutor in 2001. At the end of 2001, only one piece of representative machinery had been included, and only the set of static equilibrium icons. Nevertheless, most of the desired characteristics of the software had been completed. This included the methods of manipulating the images, manipulating the icons through pop-up selections, rotations, and distortions, diagnosing the answers, and authoring new problems. It was therefore possible to prepare up to nine problems in statics with one piece of machinery, and to test the software with novice designers. The Tutor was mounted onto fileservers at university A, and onto a smaller number of stand-alone PC's at university B.

The evaluation comprised the following sequence:

1 Conceive a problem that could be set in the MOMUS Tutor, and set the problem on paper.
2 Administer the problem to students at the respective universities, allocating credit points for correct solutions. These problems, which only required the placement of two or three force images, were intended to require only about 5 minutes of effort.
3 Collect the alternative solutions and group them into identical (or near-identical) sets.
4 Code the most common of the sets of solutions into the Tutor, along with the associated feedback comments. (Across the four problems set during the first half of 2002, there was an average of 18 different sets of solutions coded per problem. This coding took an average of 1.5 hours per problem, following an average of 1.5 hours to define each set from the 300+ students' attempts on each set).
5 Encourage some students to seek the solutions to the problems via the Tutor.
6 Administer a similar problem, and dissimilar problems involving the same principles, to all students, and seek differences in the success rate between students who have used the software, and those who have not.

Results of the evaluation

Four different problems on the equilibrium of the parts of the doorstop machine were administered on paper during the first half of 2002. These included the basic, 2-force single moving part through to the more complex three-force 2-part doorstop assembly. Students at the two universities attempted these problems simultaneously. Because of earlier experiences (Field, Burvill and Weir 2001) the authors were not surprised at the low success rate of their students: only 1%-5% of the students created correct solutions to each of the tasks.

The most common solutions for each problem were coded into the Tutor and students at university A were given access to those solutions one week after they had attempted the problem. For a variety of reasons, only a few students took the opportunity to explore the solutions and find out how well they had performed, or to seek the 'correct' solution.

Following the fourth problem, a fifth test problem in equilibrium was set, representing an abstract 2-piece object with one external load, and two support points. The abstract object could be analysed with exactly the same set of force images as was one of the four tasks set on the doorstop, but the similarity would not be immediately obvious to a novice designer. Students were also asked to indicate how much time, if any, they had spent using the Tutor software during the previous month.

Although only a small number of novice designers at university A indicated that they had used the Tutor, 50% of this group reached the correct solution for the fifth problem, whereas only 5% of the remainder of the novices did so (consistent with the capabilities of the group found in earlier tests). This was not conclusive evidence that the Tutor had increased student skills in the area, but at least the results were encouraging. An alternative explanation: the self-selection of students who used the Tutor may have biased this group to contain more educationally-motivated students, who may well have found alternative sources of learning. Ethical and administrative obstacles precluded the authors from using fully randomised groups.)

In the main evaluation study, students at university B were not given access to the Tutor until the classroom tests had all been completed. However, their final examination in the design subject was to include a fifth doorstop equilibrium problem, another more abstract problem in static equilibrium (comprising a multi-segmented loaded ring), and a set of questions relating to their use of the Tutor. Four more potential doorstop problems were coded into the Tutor, making a total of eight, and students were told that one of the four new problems would appear on the examination. None of those four new problems contained the correct solution, or useful comments if students attempted to solve them in the Tutor. It was expected that some students would try to use the Tutor on the first four problems before they accessed the four new problems, but that some students would rely on others to 'find' the new problems for them, and therefore not access the Tutor at all.

The examination results were analysed to distinguish the achievements of those who had used the Tutor from those who had not. The results indicated a significant correlation of 0.33 between the number of problems solved using MOMUS Tutor and success on the examination problem. Cross correlations with other possible causes for differential performances were not significant. (For example, there was no significant correlation between the success on the examination problem and success on the test problems throughout the semester, nor between success on those test problems and usage of the MOMUS Tutor). It was concluded that the most likely cause of better examination performance was the successful exposure to problem-solving with the Tutor software.

Discussion and comments

The encouraging findings from the evaluations of the Tutor led to minor refinements in the diagnostic routines and the expansion of the hardware and icon sets to include a four-stroke engine and the elements used for representing columns, beams, shafts and tensile members (Figure 3). The engine image can be animated continuously, or stopped in various critical configurations. By de-selecting (ghosting) external components, such as the crankcase, images of all the important separate parts can be seen, selected and magnified for detailed study. These new aspects to the Tutor allow the generation of both static equilibrium and structural elements for both pieces of hardware. During 2003, it is intended that some of these combinations will be tested in a similar manner to those reported earlier.

In separate projects, groups of senior undergraduate designers have identified hardware that would be motivating to junior designers, and have identified the types of modeling tasks that have been found most difficult. These have included the subtleties of dynamic and kinematic analysis, and the selection of manufacturing processes.

The universities are also supporting a refinement of the process for setting up the initial student attempts, by eliminating the need for paper-based 'tests'. An on-line 'Agent' (Juan et al 2002) will capture student test submissions generated from within MOMUS Tutor, and feed them in summarised form to the educator. Student attempts may then be assessed, and accessed through the 'edit' feature in MOMUS Tutor, where the feedback comments can be appended. When students then re-visit the test problem as a tutorial task, they will have the opportunity to work toward the solution. The Agent will again be able to capture student responses to the feedback comments, feeding them back to the educator, who will be able to determine if the feedback appears to be misleading, or perhaps add intermediate solutions to the set of student responses so that more efficient learning takes place. The overall aim of this latest MOMUS Tutor development effort is to reduce the gulf that exists unavoidably between educator and student in computer-mediated learning environments.

The encouraging outcome from the evaluations has also led to a separate project at University B to use the basic shell of the MOMUS Tutor with a special set of photographic images of various mechatronic devices, along with new drag and drop labels, to provide an introduction to the separate discipline of Mechatronic Engineering. There is a long-term plan to extend this approach into other engineering and non-engineering disciplines where convenient customisation, author accessibility, and immediate student feedback on modeling tasks are desirable educational goals.

Conclusion

The electronic tutor gave valuable learning experiences to the students who used it in the solution of classic problems in static equilibrium, and assisted in improving a universally weak skill. The expansion of the Tutor to include a wider range of modeling icons, and more exciting machinery, is under way.

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Development and implementation of a cross-discipline, flexible delivery unit

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Abstract: *A group project based learning approach has been developed to assist students to understand the application of complex theory to real engineering. Integrated student teams carried out the design, construction and calibration of a load cell. This was integrated with programming using Matlab and Labview languages. The project culminated in a group demonstration of the load cell accompanied by an oral presentation of the design, planning and manufacturing processes. The unit was modified in the second year of delivery to increase the emphasis on formalising the development of group work skills. The flexible investigation and design paralleled the more formal teaching process; utilising self paced learning and group interaction. The unit aimed to assist students to develop the ability to conceptualise engineering problems and put the theory studied in other units into practice.*

Keywords: *collaborative learning, flexible delivery, project based learning*

Background

As part of the on-going development of the Engineering course structure at the University of Tasmania, a new unit was introduced into the curriculum in the Engineering School in 2002 as a teaching and learning initiative. The unit, "Experimental Design and Analysis", is a compulsory second year unit, for students in all Engineering streams. The unit was developed with the support of a Teaching Development Grant from the University's Teaching and Learning Committee.

The impetus for inclusion of this unit in the course arose from a number of sources. Both the IEAust and the University of Tasmania have stressed the need for graduates to develop a set of generic skills during their degree program. The attributes required by the IEAust formed a specific set of exemplars of the more general attributes desired by the University. The skills focussed on in the development of this unit were "Ability to understand problem identification, formulation and solution", "Ability to function effectively as an individual and in multi-disciplinary teams" and "Ability to solve problems with minimal guidance".

A second driver was a general restructuring of the engineering degree program at the University of Tasmania. The Tasmanian degree provides general coverage of six engineering disciplines in the first three semesters of the course, and students have the benefit of being able to defer selection of a specialisation until after first semester of second year. The disciplines are:

- Civil Engineering
- Mechanical Engineering
- Mechatronics Engineering
- Power Systems Engineering
- Electronics and Communications Engineering
- Computer Systems Engineering

The new unit described, is the only one in the final, common semester that provides the students with an integrated experience across the broad spectrum of engineering disciplines, before they are required to finally choose their discipline. The unit was designed to encompass aspects of all major engineering disciplines, in addition to providing students with some exposure to group work and team dynamics. The engagement of international students in the group learning process was identified as an additional goal of the project. The School has one of the highest percentage levels of Full Fee Paying Overseas Student (FFPOS) in Australia. The School ended 2002 with 230 domestic students and 100 FFPOS (on an EFSTU basis).

Unit description

Course work and project

The new 12.5% unit entitled "Experimental Design and Analysis" was first delivered in 2002. The unit is included in the first semester of second year engineering, and is compulsory for engineering students from all disciplines. After reviews of the unit in 2002 some changes were made, based on both student feedback and reflections of the academic staff involved in the project, before delivering the unit in 2003. Future refinement of the School's programs may entail the unit becoming a first year subject, to provide students with early insight into the application of multidisciplinary engineering projects.

The unit delivery format consists of one hour lecture, one hour tutorial and three hours laboratory per week. Specific theory relating to the project (cantilever design, introduction to strain gauges) is covered early in the semester, and the remaining lectures cover various aspects of experimental work. The exploration of topics is designed to provide students with the theory required to complete each stage of the project, from system and experimental design, data acquisition, probability and statistics relating to error analysis, data analysis and an introduction to instrumentation.

The project required students to investigate the use of a load cell as an object counting device. Teams of students designed, constructed and calibrated a lead cell through several phases: materials investigation and selection, programming, design, data collection, analysis and finally calibration and prototyping (Figure1).

The emphasis in delivery of the theory is on integrating the six engineering disciplines: power systems, electronics and communications, mechanical, mechatronic, civil and computer systems engineering. The laboratory time is divided between formal instruction in programming languages Labview and Matlab, which are required for the project; formal introductions to the project; formal instruction in the application of strain gauges; and, from 2003, formal workshops on group dynamics. The remainder of the laboratory time is allocated to group work for the project, and staff and laboratory space are available to student teams. The number of students in the unit varies depending on domestic and FFPOS intake but historically about 80 to 110 students would be expected to be enrolled each year.

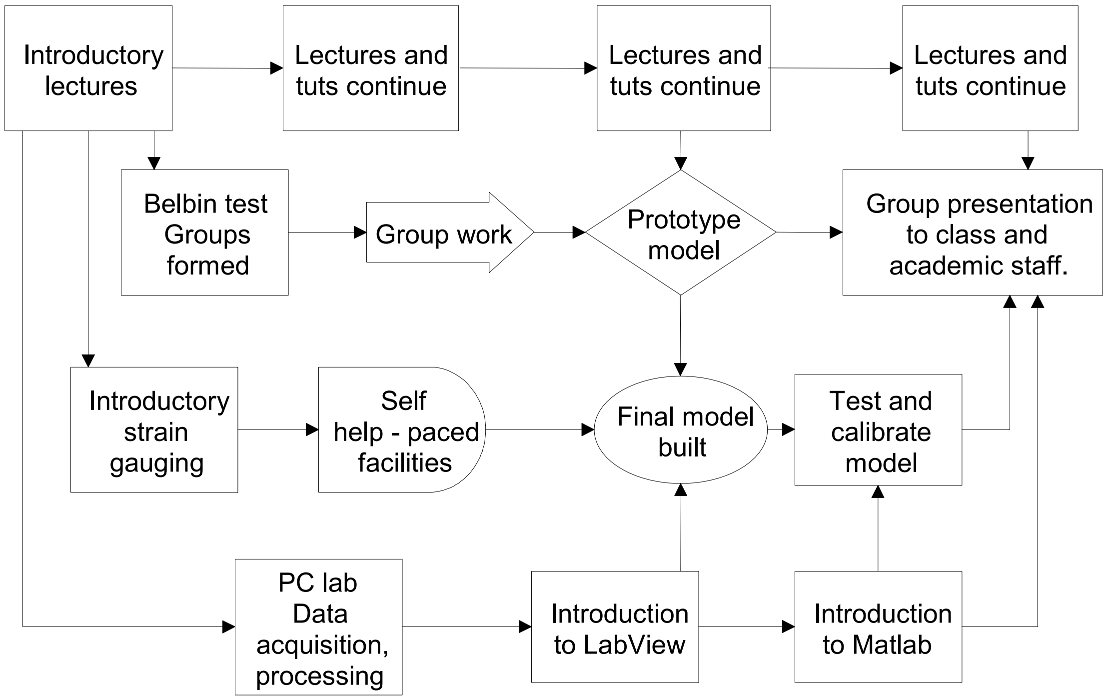

Figure 1: Parallel work streams in the unit

The latest innovation in the unit is the incorporation of a large component of project based learning and the assessment criteria. Small teams of four to five students are formed in week one with the goal of completing the semester long project. The team work parallels the more formal and traditional lecture / tutorial / laboratory form of subject delivery. The use of project based learning has been found to be an effective means of encouraging the development of and attitude towards life long learning skills [1,2].

The group project approach was designed to enhance and promote self-management, project planning and communication skills in the participating students. The material covered in lectures and the team project were designed to consolidate general engineering theory from units the students had previously covered in first and second year. Student teams obtained data on materials, strain gauges and amplifier properties using their own investigation skills; carried out their preliminary work in School laboratory space; completed analysis at their own pace and used the design process to integrate the project with academic teaching and instruction.

The group project also enabled student teams to consult with technical and academic staff on a more informal and peer level basis. This improved dialogue between the parties, and established a more peer-orientated approach. For the project, the staff operated less in an instructive mode and more as external consultant engineers, or facilitators to each group.

Group work

In order to fully develop the students' understanding and appreciation of team work and group dynamics, it was necessary to include some explicit instruction and discussion of these issues within the course. Students are often given group tasks to complete, and assessed on their ability to work in teams, but too infrequently is any formal instruction provided to students on this important aspect of project work. The staff involved in presenting this project, as well as external reviewers of the degree program, both considered it likely that students could improve their performance in this area.

Students were given material on group work in a formal session after the project had been initially defined. The Belbin test, which is a well accepted means of classifying individual traits [3] was discussed in class, mainly with respect to how the test could be used to optimise team member selection. Each student completed the test individually. The test was designed to highlight to the students the different roles that people play in teams. The attention to group work was increased in the second year (2003) of running this course as a result of reviews undertaken in 2002. One other alteration was the formation of the groups, in 2002 the students arranged themselves into groups, but in 2003 the groups were assigned by staff before the start of the semester. The selection of groups was nominally random with attention given to distributing overseas students evenly amongst the groups. Other changes to the unit, and group work are discussed in the next section.

Unit development

During and subsequent to the delivery of this unit in 2002, material for review of the subject was collected in the form of informal comments from students and student questionnaires (both formal University of Tasmania SETL (Student Evaluation of Teaching and Learning) forms and informal questionnaires developed by teaching staff). Outcomes from a review of the student assessment, feedback from staff involved in the project, and staff opinion of the student presentations and assessment were also considered [4]. The main areas for attention that were highlighted are:

- Group work - formation, and background
- Balance of group vs individual assessment of students
- Integration of the subject with other units

Group work

The development of team work skills, and a basic understanding of group dynamics were identified as objective learning outcomes for this unit. In 2002 this was developed through the group project, and introduction to the concepts of team roles during a lecture. The students formed their own teams and it was recommended that they form multidisciplinary groups, and use the team role concept to achieve a productive personality mix. In their final reports only two teams (out of 20) reported having attempted to form a multidisciplinary team. Students appeared to naturally form teams based on friendship groups, and international students were confined to their own groups. Students who were new to the course, or started after the first week found it difficult to join a group.

In 2003 it was decided that students would gain a better appreciation of group dynamics if they worked in teams assigned by staff, including international students and other students who they may not have previously known or worked with. This technique certainly caused the international students to mix with domestic students. It has been observed during workshop and laboratory sessions that students appear to be more focussed on the project work as opposed to clique groups.

The formal introduction to team roles was delivered in workshop mode in 2003, to classes of 25 - 30 students representing six project teams. The importance of developing team work skills was discussed in the context of generic attributes of graduates and examples of job advertisements and position descriptions. An overview of the stages of group formation, background to different personality types and learning styles was presented. Students then completed the Belbin test, and students reviewed the outcomes of the test with their group.

Finally, the group discussed and set out their objectives and ground rules by completing a team charter. This charter will be used in reviewing the groups' progress in team work as well as the technical output during the course of the semester. These changes to the material discussed in relation to team work and group dynamics, and the workshop format of delivery where project teams work together is felt to emphasize the concepts being delivered. The modified course will be reviewed late in the semester to assess whether this objective has been reached.

Student assessment

The merit of various methods of assessing students, particularly in units that aim to develop teamwork skills, has been the subject of much discussion during recent years [5]. Issues such as over-assessment, quality of assessment, equity and participation, web-based approaches and the balance between formative and summative assessment have been widely debated.

The assessment for this unit is entirely based on coursework, a large proportion of which has been described to be group work. A balance was sought between individual and group assessment, so as to provide the required level of individual feedback, without detriment to the aims of the unit. In the first year of the course it was found that when marked against the criteria that had been set, the student assessment was higher than the distribution of grades generally considered to be "acceptable" by the School and Faculty. This is a typical outcome of units with a high proportion of group work, concentrated in a single project. In this case, it also reflected a large time commitment made by the students to the projects, particularly in the final weeks. However, it was decided that the balance of assessment should be shifted slightly back towards individual achievement, particularly focussing on evaluating independent performance of students. The outline of student assessment handed out to students in the first week of lectures in each year, were as shown in Table 1.

Assessment Task	Mode	2002 weighting	2003 weighting
Tutorial	individual	10 %	10 %
Test	individual	10 %	20 %
Progress report	group	10 %	5 %
Assignments	individual	10 %	20 %
Design report	group	50 %	30 %
Presentation	group	10 %	10 %
Independent project review	individual	-	5 %
	Total	30 % I / 70 % Group	55 % I / 45 % Group

Table 1: Student assessment task weighting

An assessment of the impact of these changes will be made after final allocation of student grades for 2003.

The assessment tasks have been designed to direct the students to achieve the learning outcomes that have been set for the unit and to assess their performance in relation to the development of specific generic skills. The relationship between the learning outcomes, assessment tasks and the generic attributes is shown in Table 2.

Learning outcome	**Assessment Tasks**	**Generic Attributes**
Manage project development, teamwork and communicate project outcomes	Progress report, presentation, design report, independent project review	Ability to communcate effectively, not only with engineers but also with the community at large Ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member
Understand the processes of obtaining experimental data including the design of experiments and the use of basic instrumentation	Tutorial, test, presentation	Ability to apply knowledge of basic science and engineering fundamentals Ability to undertake problem identification, formulation and solution
Understand the limitations of measurements and apply this to expressing experimental uncertainty	Tutorial, test, presentation, design report	Ability to apply knowledge of basic science and engineering fundamentals
Assess the validity of hypotheses using experimental data and statistical analysis	Tutorials, test	Ability to apply knowledge of basic science and engineering fundamentals
Use and modify software tools to facilitate data acquisition and analysis.	Assignments, design report, presentation	Ability to apply knowledge of basic science and engineering fundamentals Ability to undertake problem identification, formulation and solution

Table 2: Relationship between learning outcomes, assessment tasks and generic attributes

Unit integration

The material delivered to students in the formal lecture series was intended to provide them with skills in error analysis, experimental design and data processing. This material now has a general focus and should be able to be used by students to enhance the experimental laboratory programs in other subjects that they study. It was intended that the unit would draw heavily from KMA150 and KNE112 and lead into KNE232 and all units that have an experimental or laboratory component. However in 2002, this material was taught using general examples specific to this unit. Some students may have made the connection to use the information in other subjects, but the majority did not. In 2003 the formal lectures on experimental uncertainty analysis and data analysis will be followed by tutorials that focus on applying the techniques to sets of data that the students have measured in the laboratory component of the other subjects they are concurrently studying. This will more clearly integrate this formal training in experimental analysis, with the practical training they receive in the other units in the degree program.

Project outcomes

Impact on student learning

The modifications to the teaching program have improved student learning in a number of essential areas.

The project-based unit has enabled participating students to develop their communication skills by learning in context. The group work has encouraged them to use flexibility in approach, generate dialogue and assist in their preparation for the real world of unstructured learning. Since the work was project based there was a sharing of skills among the team members and development of the "team spirit" concept that is a very important aspect of professional engineering practice.

Students were able to enjoy self-paced learning, within the general guidelines set by the School. Students were required to meet goals over the semester to ensure that individuals did not lag too far behind their peer group, and thus subject themselves to undue hardship and distress. Students enjoyed a more stimulating exploration of engineering principles and better resources for learning.

These outcomes were most clearly demonstrated by the final student presentations. Students were given 10 minutes to demonstrate the operation of their load cell, and give a short presentation on the design, construction and calibration aspects of the project. As all students complete essentially identical projects, the academic staff suggested to them, that they give the presentation a "sales pitch". The student presentations demonstrated enthusiasm for the subject and innovation. The presentations included such special guests as a giant chicken, cricket team members, television sales program hosts amongst others and students used video and theatrical skits as well as power-point to deliver a series of entertaining presentations.

Student perspective

A student questionnaire was used to measure the effectiveness of this unit. The questionnaire was completed by students in the week following the student presentations in 2002, and will be given to the students at the same time in 2003. The questions and results of the 2002 questionnaire are summarised in Table 3. One student commented on the questionnaire sheet "While I was working on the project I suddenly realised that this was what Engineering was all about".

	Question	SA	A	N	D	SD
1	Working on the load cell project helped me to understand the application of the theory taught in the course	23.5	76.5	0.0	0.0	0.0
2	Working in a group allowed me to achieve a better result than I could have alone	23.5	55.9	17.6	0.0	2.9
3	I enjoyed presenting the results of my project to other students in the class	26.5	26.5	29.4	17.6	0.0
4	Sufficient time was allocated to the project over the semester	26.5	67.6	5.9	0.0	0.0
5	I felt that I could access extra information from technical and academic staff when I needed it	0.0	73.5	20.6	5.9	0.0

6	My group had sufficient time using the data trolleys and laboratory space to complete the project requirements	8.8	58.8	23.5	5.9	2.9
7	The laboratory sessions provided me with the skills and information required to tackle the group project	14.7	67.6	17.6	0.0	0.0
8	Presentation of the project allowed me to demonstrate what I had learnt in this subject	8.8	47.1	35.3	8.8	0.0
9	The group that I was a member of worked and cooperated well together	29.4	61.8	5.9	0.0	2.9
10	In my group all members made an (approximately) equal contribution to achieving the project goals	17.6	50.0	14.7	11.8	5.9

SD= Strongly disagree
D = Disagree
N = Neutral
A = Agree
SA = Strongly agree

Table 3: Unit Questionnaire (Results in percentages)

Questions one and two indicate that broadly, the students found that the project fulfilled the aims of both helping them to understand and apply the theoretical coursework, and that they achieved more as a group than they could have individually. The common problem of distribution of tasks within the group was highlighted by question 10, indicating a wide spread of opinion on whether the group work was spread evenly amongst members. The increased focus and training in group dynamics will be assessed when this questionnaire is repeated in 2003.

Conclusions

The development and implementation of a new unit called "Experimental Design and Analysis" has been described. The unit was introduced to the second year engineering course at the University of Tasmania in 2002, and has been refined for delivery in 2003. The course was designed to give students an introduction to the multidisciplinary nature of engineering projects, and to provide the students with experience in working in teams to complete such projects. The group project was run throughout the semester, and students were able to work at their own pace using resources available in the laboratories. A lecture series was run in parallel to provide students with formal instruction on aspects of the project throughout the semester.

The results of student survey and student feedback from the first delivery of the subject show that the students enjoyed the experience and found that they had achieved more working in groups than they could have individually. Review of the subject has led to an increase in the amount of formal instruction in group dynamics and a requirement that the student teams be allocated by staff, rather than from 'clique' groups. The balance of group and individual assessment has been altered to increase the level of individual assessment. This has been done carefully, to ensure that the students maintain an emphasis on building group work skills as a major learning outcome of the unit.

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Acknowledgement

This project was funded by a Teaching Development Grant provided by the University of Tasmania.

Something Old, Something New – A Novel Approach to Web Integrated Teaching in Engineering Management

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Abstract: *This paper presents an approach to the design and development of a web based-method of teaching engineering management used by the author. Although the method is novel in the author's experience of web-based teaching, the approach implements elements from the early days of 'teaching machines'. The paper discusses the links of the approach to the historical context.*

Keywords: *web-based delivery, multimedia education, engineering management*

Introduction

The idea of automated teaching has recently become attractive with the development of the web as a convenient technology, the budget pressures on universities and the desire to make materials available for students at times and places that suit the student. The idea can be traced to Simon Ramo (1958) who observed that technology was growing to dominate the world, and that automation is demanded in complex situations, particularly where it is difficult to locate enough qualified people to do the work. Ramo's vision of automated teaching contained a number of elements, such as multi-media presentation and student paced learning that have influenced the author's development of web-based teaching materials for an engineering management course. Ramo's vision went beyond the things that have been attempted in the current implementation, and are only now the subject of experimental development, such as remote laboratories. No wonder Ramo's paper ends questioning whether the ideas presented are ridiculous.

Contextual parallels then and now

Sputnik I, 1957, removed the complacency in being the best that the USA had previously held (Bevis, 1958), and this rapidly revealed a shortage of engineers and technicians. A quick industry response was to hire academic staff at salary increases of 50-100% (McCann, 1957, Staiton, 1958, Stewart, 1958) resulting in decrease in the number of teachers. At the same time there was a desire to increase the supply of technical personnel in order to feed the cold war defence effort.

This situation created a desire to efficiently and effectively teach students so that the graduation rate per academic would increase.

The current situation in Australia has seen a decrease in university budgets resulting in more work per academic staff member, and parallel expectations of increasing pass rates, in our case resulting from a definition of efficiency. In addition, social pressures on students, such as the need for part-time employment, and general Generation X/Y expectations of flexibility make means to provide student directed learning processes attractive if the processes do not demand personal activity by the instructor at all times.

This situation creates a desire to use web-based teaching processes. Management seem to regard web-based teaching means as reduced labour means to teach, and academic staff have various motivations for using the medium, but because of the substantial preparation required, labour saving is not a motivation.

The Early Vision

Weimer proposed the idea of machine teaching using video, audio and testing machines and student paced delivery based on comprehension demonstrated in tests, in order to allow the teacher time to inspire students (Weimer, 1958). Skinner (1959) demonstrated great foresight into the potential, and differences, of machine teaching in comparison to traditional methods. Machine mediated instruction requires that the instructor use the machine to build up a logical construction of the content, and not merely deliver materials designed for another medium. Skinner envisaged a subject be taught with the use of a large number of ‘frames’ (order 10000 to 20000) to logically construct the subject. This is because in face-to-face situations teachers often set confusing situations to force students to think, and the teacher facilitates the thinking process, but in the machine situation the student must be logically guided, unambiguously. In addition, immediate feedback concerning student comprehension is vital to learning and reinforcement of material. Stockman suggested that machines should be used in teaching of the dull sections of material to take advantage of their ‘patience’ and lack of bias (Stockman, 1960). Braunfeld and Fosdick (1962) created an electronic book for teaching that required that the student provide a correct response to a quiz question in order to progress. A system of this kind provides useful feedback to the teacher concerning the effectiveness of presentation of ideas through logs of student interaction, and can enable the instructor to identify weaknesses in presentation of matters that seem obvious to the instructor. In the early period the notion of automation of teaching was controversial, in relation to both its possibility and process, and seen largely as a ‘blue sky’ issue (Le Page, 1960).

Ley (1961) presented the idea of using machines to survey student understanding across a class through the use of randomised multiple choice questions with computer analysis of responses, a goal of many current instructors in web-based teaching.

Strum and Ward (1967) reported a 1965 experiment with an IBM instructional system and found many problems that remain difficulties including the problems of user interface, machine interpretation of the instructional significance of student answers, and the cost of hardware, software and materials development. They also noted the need for an intuitive student interface, to avoid overshadowing the content with system use procedures (Strum and Ward, 1962). Alton and Fromm (1967) observed that simulation is an effective tool for teaching only when students can vary parameters in the system and observe the effect rapidly, which is a facility that can be offered through the use of hybrid computing and now with desktop systems, but was not practical when using mainframe machines.

Typical web teaching methods

Many people have experimented with web teaching methods, reporting their attempts in various venues. The work on real implementation of web teaching commenced in the mid 1990s as Internet technology, including web browsers began to become commonplace. Prior to this some attempts, such as at UniSA Flexible Learning Centre, had been made with technologies such as Windows Help tools and using SGML documentation tools. The great benefit of web browser technology is the variety of functionality supported by the standard, and the authoring tools now available, and cross platform support for the technology. This improves the effectiveness of developmental efforts and the usability of resources developed independent of the location and platform of the student.

The early work in electronic teaching materials followed from the tradition of external/distance teaching methodologies. This created a paradigm of collection of materials into a CD-ROM for distribution as the electronic equivalent of the reader pack distributed to the student, but with a much lower mass, and so providing a number of reproduction and distribution cost benefits compared with paper products. Another trend change caused by the technology change has been a shift from CD-ROM distribution to web server distribution, allowing the instructor the advantage of varying the materials visible to students during the teaching interval, either as part of the original teaching plan, or in response to difficulties that might arise with a particular class.

Some authors have reported attempts to provide interactivity with materials in order to develop student understanding of the concepts through use of simulation tools as part of the hyper-media use of the web-based presentation, for both whole courses and for illustration of parts of courses, or for application of formative or summative assessment processes (Bathgate *et al*, 1998, Bereen, 1998, Bhattacharyya, 1999, Billingsley, 2001, Doulai, 1997, Jenvey and Kaminskyj, 1997, Kaminskyi and Chapman, 1997, Machotka *et al*, 1999, Nedic *et al*, 2001, Palmer and Tulloch, 1999, Patterson *et al*, 2001, Ramer and Tang, 1999, Scott and Stone, 2001, Shortis and Woodhouse, 2001, Yeung, 1997). The idea that web-based delivery is necessarily different than classroom delivery is only rarely discussed (Boles and Pillay, 1999, Hussman and Bigdeli, 2002, Lam *et al*, 1998, McInnerney and Roberts, 2001). Chapman discusses the difference between web-based and traditional delivery as a function of the development effort (Chapman, 1998). The general theme that comes through these various works is the concept of web enabled teaching being an alternative approach to traditional classroom based methods, possibly used in parallel with classrooms. Thus, web enabled teaching primarily adds the anywhere anytime accessibility of web materials, but the form of materials varies from large, static documents of lecture note materials, through to animated demonstrations of phenomena, with interactivity provided. Most authors have described either custom software developed for the demonstration of a particular phenomenon, or the development of teaching materials within the framework envisaged by the developers of the chosen authoring tool. Authoring tools permit of possibilities such as the provision of static materials, interactive demonstrations, and formative and summative quizzes.

Systems Engineering Management N (SEM)

Systems Engineering Management N, SEM, is a second year undergraduate course in engineering management topics including, work and organizations, project, product and technology life cycles, requirement definition and requirement reticulation to specific product subsections, project related finance and the decision to proceed, and an introduction to several approaches to quality management. This has been discussed in an earlier paper (Ferris, 2001).

The course was taught first in 2001 using a full-text lecture note book, 250 A5 pages, 10 point. In addition a set of hard copy readings was provided for students. During the 2002 presentation of the course the lecture note materials were transformed into an interactive web-based form, and used in parallel with the remaining copies of the first print-run of the hard copy lecture notes. The delay resulted from difficulties associated with use of a new web materials development system, and encountering several problems not anticipated by the administrators.

The 2003 offering of the course has some readings materials accessible through the electronic library facilities now permitted by copyright law.

SEM web implementation

The author took a 250 page set of full-text lecture notes developed for the SEM course and translated them into a web presentation reflecting application of the ideas of Skinner (1959), Ramo (1958) and Braunfeld and Fosdick (1962). These source ideas were used because they provided a vision of means whereby the student can gain value from a web delivery of the material through gaining feedback on the student's ability to understand the content, at least at a superficial level. Thus, students are prevented from progressing through the material if they have not absorbed the material well enough to make a correct response to an elementary question.

The course is divided into a series of topic segments, reflecting the course syllabus statement, roughly corresponding to a chapter in the lecture notes. Each of these segments is broken into several sections presenting identifiable topic areas. These are the student interface level of the course presentation, providing a series of entry points into the study materials. Each segment is further divided into between three and fifteen 'pagelets', corresponding to roughly a paragraph of the lecture notes. The pagelets contain text, explaining a segment of the material, and where appropriate figures and equations. There are about 1500 pagelets.

In most cases of presentation of equations there is a link to a spreadsheet implementation of the equation, often including a plot of equation output, so that students can vary one or more critical parameters and observe a plot of the effect of that variation. This is provided to enable students to have experience of both the analytic and the numerical/empirical form of equations, with the latter being valued as a means of developing an intuitive sense of the significance of that represented by the equation.

Each pagelet ends with a 'Next' link, which delivers a simple multiple-choice question, having between two and four possible responses. The responses to the question are each created as a link, and the answer is expressed by choosing a link. The response produces a further page with the judgement of the response: 'Correct' or 'Wrong', and a short explanation of why that particular response is either correct or wrong. The response pagelet ends with a 'Next' link, which either gates the student to the next pagelet, or returns the student to the original, in the case of a wrong response, Figure 1. This approach is based on the view that if the student has incorrectly understood the first pagelet on the first reading, simply being returned to that pagelet will not result in correct understanding. However, an alternative expression of the concept is likely to result in improved understanding, and reinforcement when the student is informed that a correct understanding has been achieved.

All the questions have at least one correct response, but many have more than one correct response, and in a few cases all the responses offered are correct. This is because such an approach is easier to produce, and reflects the author's view that:

- the value of responses is enhanced if all the possible responses appear plausible because plausible responses demand that the student think;
- correct responses may be easy to identify, because obtaining a high proportion of correct responses on first attempt is encouraging to the student;
- the purpose of the quiz is to cause the student to pause and to reflect upon the content just read, and to consolidate knowledge and understanding obtained.

These web materials are combined with lectures presenting the highlights of the topics for the week, rather than a full exposition of the details, tutorials built on seminar presentations and discussion to build ability to argue about the course substance, and other assignments to develop and assess other course related abilities.

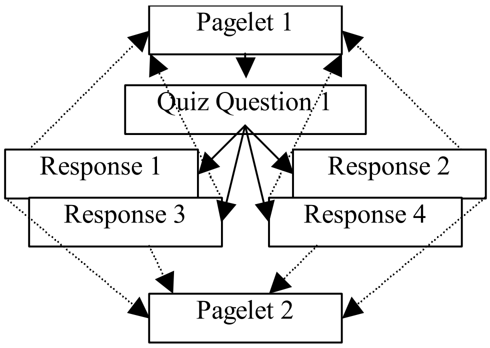

Figure 1. A state diagram of a typical pagelet and quiz question block.

Difficulties encountered

The teaching method that I proposed was different than that of other web teaching resources that the University had supported. The majority of other users had implemented approaches involving the placement of large sets of lecture notes, course notices, discussion forums, and formative and summative quizzes. This is because the software used in the corporate system was designed to address the needs of more traditional approaches to the formation of web-based delivery of content. However, the number of resources required is normally small. In contrast, the structure of my course required a very large number of small pages. This caused a problem with encountering an undocumented limitation of the software. The software could only handle a total of 32k characters in the full path file names of the entire set of files. It took a month to identify the cause of the total collapse of the system following addition of files to the space. The solution turned out to be simple, place only the files that needed to be visible in the learning resource in the learning resource directory space, and have all other files in other directories on the same server, where their file names do not contribute characters toward the 32k limit.

The major difficulty encountered related to the development effort required. The developmental steps were:

1. Production of a full text set of lecture notes, approximately 250 pages, 10 point A5. This was distributed as a book in the first year.

2. Transformation of the full-text notes into the interactive web format. Equivalent of several weeks of work. This had two stages, the intellectual plan stage, and the clerical editing of files and creation of links. The latter was done personally for lack of clerical support.

Future growth

The current state of the interactive web presentation is considered by the author as a recognizable stage in the development of the materials. There are several directions of future enhancement envisaged.

1. Development of PowerPoint lecture presentations for topics, including audio and self play features. This format has been used by others for presentation of content in web-based distance materials, and has the advantages of providing information transfer in a different physical form, which may suit some students' learning style better than a text based approach.
2. Organization of electronic library resources, following recent changes in the copyright law allowing University libraries to hold materials, subject to limits, in scanned electronic form for distribution to enrolled students. This process allows the creation of links to the course web page, because the course web page access is limited to students enrolled in the course. Materials that it is planned to make available include book chapters, journal articles and magazine and newspaper articles that are relevant to the essay topics of the course.
3. Development of the course into an external/guided study mode course. This will provide the advantage of allowing greater flexibility for students in their progress in the course by reducing or eliminating the dependence of students on attendance at classes. To this end, the course has been offered in an external mode over the summers of 2001-2002 and 2002-2003 to very small numbers in each case, primarily as means to gain experience into the issues associated with these modes using the currently available course materials. The current opinion of the author is that it is desirable to maintain the tutorial classes for any student cohort where the number of students is great enough to have a tutorial class of about 12. The benefits will be both pedagogical, with the students gaining from the class interaction, and administrative, with classes being useful for student/instructor interaction.

Conclusions

This paper has presented an interesting history of the development of machine assisted, student paced, multimedia teaching methods. It is interesting that some of the earliest work, long before such systems were nearly practical, was speculative work performed in the early period of computing. The ideas expressed in the early dreams have only recently become practical.

This paper has also presented an application of the Skinnerian approach (Skinner, 1959) to mechanical teaching, as moderated by awareness of the ideas of Ramo (1958) and Braunfeld and Fosdick (1962), in the technical area of engineering management, indicating what such a project entails with current web development tools, and what such materials may be.

The author is still exploring the issues of student response to the materials, and means to augment the materials with further enhancements that add additional value to the system.

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Teaching Engineering Creativity at Tertiary Institutions

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Abstract: *In this paper results of 20 years of experimenting by the author in teaching engineering creativity in Australia and overseas are discussed. Teaching approaches and materials are presented and problems and difficulties encountered with these approaches are analysed.*

Keywords: *engineering creativity, tertiary institutions, teaching*

Introduction

Engineering creativity is a topic that continues to generate hot discussion and polarise points of view. Confusion is often caused by a lack of understanding and ability to differentiate the following:

- Thinking and intelligence.
- Creative thinking and creativity.
- Problem-based teaching and systematic teaching of problem solving methodologies.
- Is it possible to teach engineering creativity?
- How does one encourage creativity?

There are clear answers to these questions and they will be discussed in the following sections.

There is a large variety of problem solving methods, such as, the ‘Try-and-see’ approach, the ‘Checklist’ method” the ‘Morphological Box’ method, the ‘Ideal Final Result’ analysis, the ‘I wish’ method’, the ‘Ah-Ha’ method, the ’Smart Little People Modelling’ method, the ‘Brainstorming’ method, ‘Synectics’, and, finally, the ‘Theory of Inventive Problem Solving’ (TRIZ) and the ‘Ideation / TRIZ’ methodology. When one is asked, “What problem solving methods do you know?” a typical answer is “Brainstorming”, and sometimes Lateral Thinking is mentioned. It is not surprising because many tertiary sector educators are unaware of the variety of problem solving methods available.

When the Institution of Engineers, Australia introduced the list of 10 generic skills (one of them was “Ability to undertake problem identification, formulation and solution”) all universities immediately responded by including in study guides and unit outlines expressions such as, “Creative thinking is encouraged through problem-based learning, brainstorming sessions, etc.). But how many universities in Australia systematically teach engineering creativity? To the knowledge of the author of this paper, there are only two or three. Many engineers and educators mistakenly think that any discussion is brainstorming, when there are strict rules of Brainstorming session preparation and supervision. Another delusion is their use of problem-based teaching and encouraging group discussions it is teaching engineering creativity.

On the contrary, in the United States about 30 universities systematically teach the Ideation / TRIZ methodology in engineering units and some have even introduced elective units based on the Ideation / TRIZ methodology.

In the early 80's the Ministry of Tertiary Education of the former USSR introduced at university level a core unit "Fundamentals of engineering creativity". Students were systematically taught problem solving methods and under supervision of leading academics participated in research. It was common for students' names to appear in research publications and patent applications. At the same time Genrich Altshuller, the founder of classical TRIZ, published his first books [1], making the theory available for engineers, researchers and educators. The author of this paper who was at that time working at the Azov State Technical University (Mariupol City, Ukraine), started experimenting with systematic teaching of engineering creativity, and developing curriculum, and teaching and learning resources. After immigrating to Australia in 1992 he continued the development of materials for teaching TRIZ and other problem solving methods and introduced systematic teaching of engineering creativity at Monash University in 1995 and at the Queensland University of Technology in 1999. His exercise book on solving problems with TRIZ [2] was published in the USA in 1999, and then translated into Japanese and published in Japan in 2000 [3]. Results of these experiments, and teaching and learning materials will be discussed below.

Is it Possible to Teach Engineering Creativity?

The importance of this issue has been well recognised. For example, during the World Innovation and Strategy Conference (WISC98), Sydney, Australia [4], new sessions were introduced, such as "TRIZ and Other Techniques", "Product and Process Innovation", "Innovation in Education", "Organisational Creativity and Learning" and "Innovation network". During conference discussions many speakers, especially from industry, insisted that creativity couldn't be taught; creativity is something that some gifted people acquire at birth (If you want to be creative, carefully chose your parents). Other speakers (e.g. Belski, and Kosse, [4] pages 194 and 239 respectively) gave examples of how problem-solving tools can be effectively used to support creative thinking.

Edward de Bono [5], a well-recognised authority on the theory of thinking, states that **thinking** is a skill that can be learned, whereas **intelligence** is an inherent capability largely determined by genes. A conference sponsored by the American Society for Engineering Education (ASEE), the National Science Foundation (NSF) and the US Department of Commerce held in the mid-60's concluded that the creative requisites of invention and innovation could be taught, but that engineering schools were not doing an adequate job.

One thing is certain, the efficiency of thinking can be significantly improved if a thinker is equipped with different problem solving tools. Methods that facilitate creative thinking can be divided into three groups:

- Methods and exercises that improve thinking (e.g. De Bono's Thinking Course).
- Methods that facilitate creative thinking when thinkers employ their own knowledge and experience (e.g. Brainstorming).
- Methodologies, such as Ideation / TRIZ, that facilitate thinking, equip thinkers with analytical and knowledge-based tools that enable them not just to solve problems, but to make scientific predictions in particular areas of engineering.

The history of the development of the Ideation / TRIZ methodology, when it flourished first in the former USSR and then in the USA, proves that creative thinking and creative problem –solving tools can be taught. The question is what can be taught and what teaching approaches can be used within the limited timeframe and overloaded programs of engineering units.

Review of Methods that Could Facilitate Thinking and Creative Problem Solving

Some approaches to thinking are known from ancient times (e.g. critical thinking); others have been developed in the 20th century. Critical thinking (from the Greek word *kriticos* which means judge) is based on the concept that if to remove "untruth", then what is left is "truth". The question can be asked as to whether successful destruction of one idea will give rise to a better one. Somebody has to suggest new solutions using problem-solving methods. Among the known methods there are very simple ones to use (e.g. the Try and see method); others, such as the Ideation / TRIZ, are comprehensive methodologies that take weeks just to learn the fundamentals and months, or even years, to master skills in using them. A review of known methods that facilitate creative thinking is given below with a brief description and analysis of advantages and limitations.

Edward De Bono is considered by many to be the leading authority in the world on direct thinking as a skill. Having background in medicine and psychology, he developed dozens of exercises and approaches for improving thinking process and originated the term "lateral thinking", which is now in the Oxford English Dictionary. Among the approaches and exercises he suggested are: PNI (positive, negative and interesting aspects of the object), APC (alternatives, possibilities choices), "L-Game", Lateral Thinking, CAF (consider all factors), CS (consequences and sequel), DRDL (dense reading and dense listening), EBS (examine both sides), OPV (other people's views), seven thinking hats, etc., [5]. De Bono's methodology is highly effective in improving thinking as a process and carrying comprehensive analysis of the object, however, it could hardly be regarded as a structured method of engineering problem solving.

The Try-and-See Method (also known as the Trial and Errors Method)
Everybody uses it, however its effectiveness is questionable unless other approaches are used simultaneously, for example the list of physical effects or analogy.

The Checklist Method
The essence of this method is in examining an object against different lists of verifying questions (checklists). Many professional inventors developed their own checklists. The author of this paper gathered several comprehensive checklists [6] that include General checklist, Problem need checklist, Fact finding/descriptive categories, Applied imagination checklist, Manipulative verbs and Searching checklist. This method can be used at early stages of design to reveal shortcomings of an existing model and often gives an insight to how it can be improved.

The Ideal Final Result Method
This method has been suggested by Altshuller as one of the tools within the Classical TRIZ, but it can also be used on its own. The essence of the method is in stating the "Ideal Final Result". There are six ways of achieving "ideality": Exclude auxiliary functions, Exclude elements, Identify self-service, Replace elements, Change the principle of operation, and

Utilise existing resources in central. This method is simple to use and often leads to good solutions.

The Morphological Box Method

This method has been suggested by the Swiss astronomer Tsvicky and includes five steps: 1. General description of the object to be investigated. 2. Revealing important characteristics and properties of the object. 3. Investigation of possible variants of obtaining each characteristic (property, function). 4. Matching these variants in a morphological matrix (box). 5. Selection and evaluation of new combinations of properties (functions).

The Morphological Box Method is useful at early stages of design and helps to find dozens (sometimes thousands) of new combinations of existing features.

The Long Period of Meditation Method (the "Ah-Ha" method)

Ah-Ha is the feeling of having an insight to a problem that has been bothering you for some time. It includes three stages: 1. Gather possible information about the object (the "sponge" stage). 2. Let your mind incubate information (the "egg" stage), and turn to other things leaving the problem alone. 3. One day the idea will come to your mind (Ah-Ha stage). Many professional inventors and scientists use this approach and can tell "success stories", for example Darwin liked showing the exact place on the walkway where the theory of evolution came to his mind. There are special exercises that can be used to improve the effectiveness of using this method, such as Daydreaming, Night-dreaming and Imagination games.

Brainstorming

Quite often people say – let's brainstorm this problem and start discussion, mistakenly thinking that this is Brainstorming. Osborn, who developed the Brainstorming method in late 1930's (www.brainstorming.co.uk), suggested strict rules that can be expressed as follows: Generate your own ideas; Pick and develop somebody's idea; Ideas can be generated in any form (serious, humorous, fantastic, etc.); No proof is required; Total ban on any critics during brainstorming sessions. Brainstorming sessions quite often result in more than 50 new ideas as a result of group thinking. Sometimes a person who generates a useful idea or an idea that leads to a useful idea has a feeling of not being recognised, and some experts think that this is a shortcoming of the method.

Synectics

Synectics is a group technique, similar to brainstorming, but where the groups are deliberately drawn from widely different backgrounds, and projection and empathy are used to obtain an alternative view of the problem. Different kinds of analogy are employed, for example, personal analogy, direct analogy, symbolic analogy, fantasy analogy, analogy with nature, and "by chance" analogy. It has some similarity with De Bono's thinking tools but with an engineering focus. Often it helps to find completely different ideas and approaches.

The Method of Smart Little People Modelling

This tool has been suggested by Altshuller as part of classical TRIZ and can also be used on its own. The essence of the method is that the required function in the model of the object is carried out by a crowd of intelligent small creatures, which, when given the order, are able to grasp, drag, pull, throw, get together, or perform any other required action. Quite often it gives insight into how the required function can be implemented in an engineering solution.

The Method of Developing an Inventor's Idea (The "I wish" Method)

This method was developed in the mid-80s in the Lithuanian Academy of Agricultural Sciences [7], by a group led by Chapiale. The algorithm includes seven steps with four different pathways within it, which are explored consecutively. The key step of the method is expressing wishes, converting them into ideas, and developing them into engineering solutions. The method includes extensive supplementary lists, in particular, 1. List of kinds of energy and energy of fields; 2. List of sensations; 3. List of different states of an object. These supplementary lists are used at certain stages of the problem solving process. The method is effective but relatively complex to use.

The Ideation / TRIZ Methodology

The letters T, R, I, Z form an English acronym for the Russian words *Teoriya Resheniya Izobretatelskih Zadach*, which, translated, mean the Theory of Inventive Problem Solving. The founder of TRIZ, Genrich Altshuller, suggested ten laws of technical system development that can be used for scientific prediction in different areas of science and engineering. He proved that inventive problems could be classified, codified and solved methodically, just like other engineering problems. When he released the TRIZ fundamentals in the early 50's, he suggested six tools that form the Classical TRIZ. They are as follows:

- The Contradiction Matrix.
  Altshuller indicated that any inventive problem contains at least two contradicting parameters. For different combinations of contradicting parameters he suggested inventive principles placed in the cells of the Contradiction Matrix. These inventive principles have been derived from real patents (more than 1 million patents have been analysed to refine and complement the Contradiction Matrix).
- Physical Contradiction.
  The essence of a physical contradiction is when a parameter contradicts to itself (e.g. to improve strength the cross-sectional area has to be bigger, to reduce weight – it has to be smaller). To resolve physical contradictions he suggested different separation principles.
- The Substance-Field Analysis (SUF).
  Altshuller suggested that in any technical system at least two substances interact through a field. To improve insufficient action, or to eliminate undesirable action another substance and/or another field can be added to the system.
- The Ideal Final Result Analysis (has been described in previous sections).
- The Smart Little People Modelling (has been described in previous sections).
- The Algorithm of Inventive Problem Solving (ARIZ), which includes all these tools and can be used for tackling highly challenging problems.

The Kishinew group of TRIZ researches led by Zlotin is the most renowned group of Altshuller's followers that contributed to further development of the TRIZ methodology. In 1991 the Ideation International Inc. was established in the United States (Zlotin is the Chief Scientist of the company). The Ideation International Inc. refined the TRIZ methodology, developed new tools, developed the Innovation Work Bench software package, and now the Ideation / TRIZ methodology in addition to Classical TRIZ includes the following new tools:

- Problem system information innovation situation questionnaire (ISQ).
- Problem formulator.
- Useful / Harmful effect analysis (SUH modelling).
- Anticipatory Failure Determination (AFD)

The Ideation / TRIZ methodology has grown into the most powerful methodology of creative solving of engineering problems. It has flourished in the USA, and TRIZ centres are established in several European countries and Japan. Unfortunately, it remains little known in

Australia. Teaching materials on the Ideation / TRIZ methodology for different user levels from beginners to advanced users can be obtained from the Ideation International Inc. (http:\\www.ideationtriz.com).

Teaching Engineering Creativity

When, in 1993, the author of this paper approached several universities in Melbourne and offered his materials for teaching engineering creativity, a typical answer was "we do not have time to teach all this". Most Australian universities still adhere to the opinion that problem-based teaching is sufficient to make students resourceful and good creative thinkers. Let's look at the problem from a different perspective. Is pushing a trainee into a swimming pool the best way of making him a good swimmer? Or it is better to teach him a swimming technique first, ie, what to do with his hands and his legs? The positive experience of leading universities proves that engineering creativity can be systematically taught without compromising the integrity of a curriculum.

The author of this paper working at Monash University and then at QUT developed arguably an optimum approach to teaching engineering creativity within a Mechanical Engineering Degree. It can be easily adapted to other areas of engineering. These teaching materials have been adopted by several universities in the USA, Singapore, Israel and Australia. Quite often the author is invited nationally and internationally to give seminars and workshops on approaches to teaching engineering creativity.

Teaching and learning approaches

In the first Mechanical Design unit "Fundamentals of Mechanical Design" taught in the second year, two weeks are devoted to systematic teaching of engineering creativity. During one lecture a review of existing problem solving methods is carried out. This lecture is followed by a tutorial and one of the exercises is a brainstorming session with an in-class assessment. Another lecture is entirely devoted to the Ideation / TRIZ methodology. Some of the problems brainstormed at the previous tutorial are solved using the Ideation / TRIZ tools to demonstrate the difference. More than 20 solved tutorial examples are available to students from the Design Web-site, as well as the course notes with detailed description of problem solving methods. The first part of the book [2] is also available to students from the Design Web-site. The IWB software is available to students at the Design Studio and computer classes. To assess skills in using the Ideation / TRIZ methodology students are given assignments including two problems. For example,

Problem 1. Using different TRIZ tools solve the following problem:

Large aircraft such as Jumbos and cargo carriers land at relatively high speeds - 200 to 280 km/h. On each landing, the undercarriage tyres lose approximately 10 kg of rubber causing them to be replaced frequently. Fig.1 below shows a typical good landing. Note the smoke (rubber being burnt) and skid marks (rubber deposited due to impact) as the aircraft lands.

Suggest methods for preventing extensive tyre wear thus increasing tyre life.

Figure 1: Boeing 747 during landing. Smoke from burning rubber tyres is clearly seen (Source: Lufthansa magazine)

Example of a solution to this problem is given below.

Problem 2. Using different TRIZ tools solve the following problem:

In space, where everything is in a state of weightlessness, astronauts are faced with problems whereby common devices work in unusual ways or do not work at all. For instance, when you use a hammer on Earth, its kickback is compensated by its weight. In space, when you hit something with a hammer, it kicks back towards your head with dangerous speed.

Modify a hammer to compensate for the kickback in space.

Example of a solution to Problem 1.

To employ the Contradiction Matrix approach, we have to identify two contradicting parameters. The parameter we are trying to improve (or maintain) is **Speed**. Deteriorating parameter is **Waste of substance**. For this pair of contradicting parameters, the Contradiction Matrix suggests the following inventive principles:

10. Prior action
- **a.** Carry out all or part of the required action in advance
- **b.** Arrange objects so they can go into action in a timely matter and from a convenient position

13. Inversion
- **a.** Instead of an action dictated by the specifications of the problem, implement an opposite action
- **b.** Make a moving part of the object or the outside environment immovable and the non-moving part movable
- **c.** Turn the object upside-down

28. Replacement of mechanical field
- **a.** Replace a mechanical system by an optical, acoustical or odour system
- **b.** Use electrical, or electromagnetic field for interaction with the object
- **c.** Replace fields (stationary with moving, fixed with changing in time)
- **d.** Use a field in conjunction with ferromagnetic particles.

So, the Contradiction Matrix suggests doing something in advance, placing an object in a favourable position, making stationary object moving and moving object stationary. Moving fields can be employed to perform the action.

I our case, the major problem comes from velocity gradient, because the runway is stationary and the tyres are moving. If we can equalize velocities (make moving object stationary) the tyres will touch the runway with zero relative velocity. An engineering solution may be to spin the tyre (preliminary action) so that linear velocity of rotation will compensate translational velocity. To drive the tyres electric motors can be used, built in the landing gear (moving magnetic field) or energy of the wind (another moving field) driving tyres by means of blade-like ribs placed on side surfaces of the tires.

Students utilise acquired problem-solving skills in the Warman Design and Build Competition of IEAust, working in teams of four. In the second Design unit "Design of Mechanical Components" students in small groups of three, carry out the first part of a project on gearbox design and continue to utilise problem-solving skills learned.

In the third Design unit "Design and Maintenance of Machinery" students carry out the second part of a group project on the development of a lubricating system for the same gearbox. One of the lectures is devoted to the Anticipatory Failure Determination followed by a tutorial on case studies of machinery failure analysis with the use of AFD. So students studying design are exposed to all Ideation / TRIZ tools and also have freedom to use other problem-solving methods as well.

These teaching approaches and systematic teaching of creative problem solving methods improved students' attitude and allowed the achievement of a high level of development of generic skills. Over the last three years failure rate in mechanical design units has been significantly lower than in other engineering units.

Conclusions

In this paper different aspects of teaching engineering creativity at tertiary institutions have been discussed. It has been demonstrated that:

- There is confusion among the engineers and educators on thinking and intelligence, creativity and creative problem solving, and whether is it possible to teach creativity.
- Effectiveness of creative thinking can be significantly improved through systematic teaching of problem-solving methodologies.
- There is a large variety of problem-solving methods.
- Review of existing problem-solving methodologies and systematic teaching of advanced methodologies, such as the Ideation/TRIZ enable students to compare and make their own judgement.
- Teaching materials and approaches used enable systematic teaching of different problem-solving methods within a limited time frame and put them to practical application through Design units and other subjects.
- Systematic teaching of creative problem solving methods improves students' attitude and allows the achievement of high level of development of generic skills, as well as contributes to the reduced failure rate in Mechanical Design units.

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Action research for generic skill development: an integrated curriculum approach to develop information literacy, critical analysis and English expression of engineering students (utilizing triangulated assessment)

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Abstract: *This paper concerns the extent of engineering students' generic skills in searching and retrieving the professional published literature and their ability to read, conceptualize and write a simple literature review. Students with a range of written English ability, including English as a Foreign Language (**EFL**) and English as a Second Language (**ESL**) are the subjects reported in this paper.*

Provoked by a paper presented at AaeE 2001 in Brisbane (Airey, 2001) an academic staff member and a librarian formed a partnership to undertake an action research project. One goal was to extend students' information literacy capabilities in a piece of integrated assessment. A further objective was to integrate generic skill development while researching a topic on sustainability. The action research project was embedded in the Mechanical Engineering unit, Energy and the Environment.

Students conducted a literature review. They were required to give a coherent account of issues raised, to describe the links and correlations, ambiguities and weaknesses of current knowledge contained in their selection of literature. Students were also asked to give their own opinions and predications of the technology studied.

A triangulated, moderated, assessment system comprising academic, librarian, and peer marker was employed. Statistical correlations between the three components were undertaken. Our findings support one of two possible scenarios: either a sizeable proportion of the student cohort had low critical analysis skills, or socio-cultural barriers to honest peer assessment came into play.

Keywords: *Integrating generic skills, Information literacy, Written English ability, Peer assessment.*

Introduction

There is tension striking the balance between measuring ***hard*** technical engineering knowledge acquired and working to develop students' ***soft*** generic skills. We term this tension the "crowded curriculum" dilemma.

In this paper we discuss our experience attempting to integrate some generic skills into an engineering unit.

There is an impression amongst many students that information obtained from the World Wide Web is sufficient for a literature review. Serious implications follow for the quality of life-long learning key to Engineers Australia (IEAust) graduate attribute requirements.

With a background awareness of these issues a teaching partnership between academic and librarian arose and resulted in the work described in this paper. The circumstances of the development of the partnership are relevant to understanding the issues of the "crowded curriculum" and generic skills development are briefly described here: the librarian has had significant experience in administering the undergraduate, postgraduate and research aspects of the engineering collection at QUT. An important part of this work involves teaching/disseminating basic and advanced skills of information retrieval and literacy to staff and students through individual consultation, workshops and seminars. It had become obvious through the course of this work that there was minimal time in the curriculum for these skills to be transferred. However, through many individual consultations it was apparent that students frequently needed these skills in tasks such as undergraduate projects. One difficulty in teaching these skills in seminars presented to students was that they were taught somewhat removed from the engineering context. The academic had been teaching the course Energy and the Environment for two years and had found that there was a plethora of information available in this area in both the Web and the refereed literature. Students had great difficulty in appropriately accessing and processing this information while taking a critical approach. One compounding factor was that energy and sustainability issues are strongly influenced by the background and/or agenda of the author. On issues such as Greenhouse, fossil fuel reserves, emerging alternative energy technologies and sustainability issues even the experts do not agree. Students needed help to manage tasks associated with the Energy and Environment course.

Thus the academic and librarian were trying to achieve similar goals and it was felt that by syndicating teaching information retrieval and literacy in the context of an actual course would enhance the objectives of both parties and provide benefit to students. A creative tension existed between the academic and librarian's skills and approaches, shared/different values and their difference in emphasis.

The Faculty of Built Environment and Engineering at QUT has been motivated by the Institution of Engineers statement on generic attributes of Graduate Engineers. Our action research project sought to enhance students' generic skills namely, researching information, thinking critically about information, English expression, coaching for improved performance.

We believe our work can fairly be described as ***action research***, as it fits most of the accepted working definitions. (Altrichter, Kemmis, McTaggart, & Zuber-Skerritt, 1991, p. 8). We began our project with the premise that our students' generic skills in the areas detailed above were wanting. We set out to measure skill levels while at the same time; we sought to improve the skills we were trying to measure.

This paper poses questions about integrating generic skills into a crowded engineering curriculum. We look at engineering student information seeking behaviours and the issue of various levels of written English language ability in a diverse student cohort. We discuss the labour required to administer this type of assessment and the value and reliability of peer assessment.

In this exercise we wanted to integrate generic skill enhancement with the acquisition of technical knowledge. The intent was for students to learn in a self-directed manner through discovering the history, developments, limitations and possibilities of energy technologies. We wanted students to read the published state-of-the art. The learning goals embodied in the set task were:

- For students to learn about sustainable energy systems, by means of researching the published literature and writing a review;
- For students to learn about sustainable energy systems by peer marking one other's review;
- Reflect on some of the contentious areas in environmental / energy policy;
- Develop critical thinking skills both by researching their topic, and by offering a critique of one other;
- Develop and enhance students' information retrieval skills;
- Develop and enhance students' writing and citing skills;
- Promote the use of peer-reviewed scholarly literature;
- Develop students' coaching skills, that is, skills developed as a peer marker.

The paper commences with a description of the course, assessment and student cohort details. This is followed by a description of the assessment

Student Cohort and Assignment / Assessment Details

Our two cohorts (one undergraduate, the other postgraduate) included different proportions of overseas students with native English, English as a foreign language (EFL), English as a second language (ESL) or non-English speaking background (NESB) as shown in Table 1.

	EFL ESL NESB	Native English Speaker	Total
MMB451 Undergrad	7	20	27
MEN175 Postgrad	22	2	24

Table 1: Student cohort language background

	Singapore	Thailand	Indonesia	Europe and Other	Australia	Total
MMB451 Undergrad	5	0	0	0	22	27
MEN175 Postgrad	2	11	2	5	4	24

Table 2: Student cohort – origin

Table 2 shows that our students' country of origin varied, with south-east Asian countries predominating. The overseas students in the undergraduate cohort get credit for half of the BEng. degree for holding an approved overseas diploma qualification.

As one of four pieces of assessment in a thirteen week semester, mechanical engineering students studying Energy and Environment were set the task of conducting a brief literature review. We suggested they research one topic from a selected range of thirty environmentally sustainable energy technologies. It was also possible for students to negotiate a topic of their own interest. Later in the semester each student got to mark one other's paper. Then the academic and the librarian's marks were correlated and moderated to give a final mark.

Students were asked to review the published literature to evaluate the practicality, viability and sustainability of various technologies and to predict future trends. We stipulated students review at least five pieces of literature, encouraging them to keep searching until they had a coherent selection of papers.

We encouraged the development of critical thinking skills by asking student reviewers to distil the essence of an author's argument. Students were asked to identify unifying threads or determine opposing points of view from a number of writers on the same topic. We asked students to distinguish between empirical fact and writers' opinions. We were also trying to test students' ability to conceptualise a topic/problem.

Students were encouraged to analyse the literature, and to construct their arguments using the ***debatable statement / debatable position*** device. A debatable statement is one that can be proved wrong by reasoned argument. This concept is commonly taught in many writing and rhetoric courses e.g., (Colorado State University. Writing Center, 2003), (Hoffmann, 2003)

Peer assessment was included in the assessment procedure. Markers were rewarded with a mark (up to five percent of total assessment) for their effort. We felt the skills student might enhance by marking are somewhat akin to those ***coaching*** skills necessary for management and supervision. Therefore peer marking could have some valid claim to build generic skills in our graduates.

Assessment Results

Our experience with the peer marking exercise mirrored that of the results of the lecturer's earlier experiment with peer marking "Students … found it quite difficult to make a critical assessment of the papers they were marking." (Brown, 2001, p. 347) This also accords with Airey who writes "It is evident that most students are reluctant to say that their work, or that of their peers is anything less than good, and that on average the students tend to overestimate the quality of their assignments. (Airey, 2001, p. 406)

In common with other researchers, e.g., (Airey, 2001, p. 407) our experience is that a peer marking exercise does not save lecturer effort. In fact, it requires a good deal of effort to administer and moderate.

The standard of written English expression overall was poor. This is matter of concern as these students were only one year away from graduation. Not surprisingly EFL/ESL students did less well.

Inadequate skills in English expression (spelling, grammar, syntax, and vocabulary) were not confined however to EFL/ESL students. Few of the native English speakers distinguished themselves with this piece of assessment.

Whilst there were a good number (about three quarters) of competent examinations of the technology, few (about one fifth) of the students produced a report that was particularly easy, or a pleasure to read. Feedback given to students when they received their mark included pointers, such as:

- Consider your reader;
- Proof read;
- Check spelling;
- Write with brevity and clarity;
- Avoid overly long sentences;
- Avoid flowery prose;
- Understand passive vs. active voice (as a rhetorical device);
- Correctly reference literature;
- Consider acquiring useful writing tools for your professional library e.g., dictionaries, thesauri, guides to modern English usage, and rhetorical style guides.

Perhaps our most important piece of advice was to urge students (as nearly fully-fledged professionals), to read more. In order to be a competent professional writer, one must ***read*** good writing. We suspect that (in general) engineering students read and interpret texts a good deal less than other students.

(Orr, 2002, p. 42) points to the contradiction that while English is predominant in practice of engineering, most of the world's engineers are not native speakers of English. Orr believes that the engineering profession needs a reliable instrument for measuring competence in engineering English. He goes on to propose the application of Douglas' "Language for Specific Purposes Test". (Douglas, 2000)

Overseas students are partly motivated to choose Australia because this is an English speaking country. Perhaps our engineering curricula have paid too little attention to the quality of English expression required of our students? Australian universities may need to guard against the lowering of written English language achievement criteria as a mechanism to cope with significant EFL/ESL populations. Should we set objective tests in English competence before we allow our students to graduate as engineers?

The primary focus of this unit is ***hard*** technical knowledge. We are perhaps uncertain of the true writing capability of students as we had relatively few marks available to give sufficient incentive. Fifteen percent of the total unit marks were allocated to the literature review. Ten for the review, and five for their marking effort. Any trade-offs in this attempt to integrate technical and generic, we term the "crowded curriculum" dilemma.

Students exhibit a clear preference to cite Web-based sources. Despite being explicitly instructed not to use public domain Web sites, a few students persisted in only citing Web sites. This accords with the findings of Philip Davis' longitudinal studies (Davis, 2003) that show a clear reluctance of microeconomics undergraduates to cite ***other*** than Web documents. One of our undergraduates wanted to know why we insisted on scholarly literature when he was ***sure*** he would not have access to such literature, as a graduate practising engineer. His perception was most working engineers are information poor, practising on the wrong side of the digital divide. It was felt that this reflected a poorly developed concept of the work of a professional engineer and it is a concern that such concepts persist into the latter years of an engineering degree.

The fact that most of our subscribed, peer-reviewed scholarly literature is available through a Web browser (via seamless IP authenticated access) does tend to blur the distinction. Information literacy education needs to equip students with skills to distinguish between edited, reviewed, scholarly writing and the public domain, unfiltered opinions and trade literature found on the Web.

Students had a poor conception of how to correctly cite literature in the text, and in their bibliography. Of twenty-seven papers, only three students cited literature without flaw or blemish.

Observations on Marking

Figure 1 shows the correlation between the librarian and the lecturer's mark for the undergraduate cohort. Native English speakers and long term Australian residents (full symbols) are distinguished from EFL/ESL speakers (outline symbols). In general the marks for the EFL/ESL students were lower than that for the native speakers, though the EFL/ESL group is small and may not be completely representative. It can be observed that there is a strong correlation ($R^2 = 0.9726$) between the lecturer's and librarian's marks for the EFL/ESL literature reviews. Presumably this indicates that both markers could more easily distinguish features in the literature reviews for which they could award marks. Two such features would clearly be English expression and evidence of a critical approach. Correlation between the lecturer's and librarian's mark for the Native English speakers is lower ($R^2 = 0.7494$) than that for the EFL/ESL students, though still significant.

When a general comparison of the lecturer's and librarian's marks is made by comparing the position and slope of the trendline it can be observed that the for the Native English speakers the librarian gave a lower mark on average than the lecturer. After discussion this was found to be because the lecturer recognized the technical content of the literature reviews where as the librarian generally found all Native English reviews were deficient in English expression. For the EFL/ESL students the same trend can be observed, though the sample is small. The lower EFL/ESL marks are particularly noticeable as being given lower marks by the librarian than the lecturer. In these items the English expression was particularly poor yet there was still a basic level of technical content.

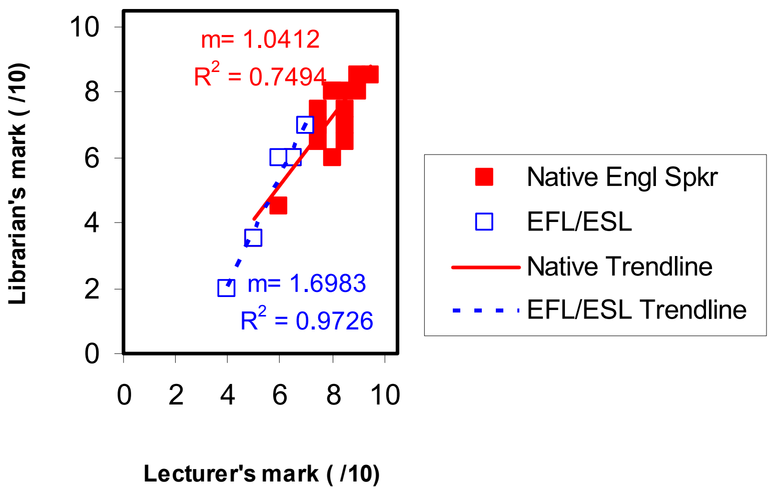

Figure 1: Correlation between librarian and lecturer's mark

Figure 2 shows the correlation between the mark given to a literature review by a peer marker and the average of the lecturer's and librarian's mark. The EFL/ESL literature reviews were generally marked by native English speakers. For the EFL/ESL students there is a strong correlation ($R^2 = 0.8244$) between the teaching team mark and the peer mark. As in Figure 1, this indicates that there were features in the work that made it possible to discriminate marks. The most obvious factors are clear English expression and critical approach. The technical content of both groups was similar. By the position and gradient of both trendlines it can also be observed that the mark awarded by the peer markers was higher on average than that of the teaching team average.

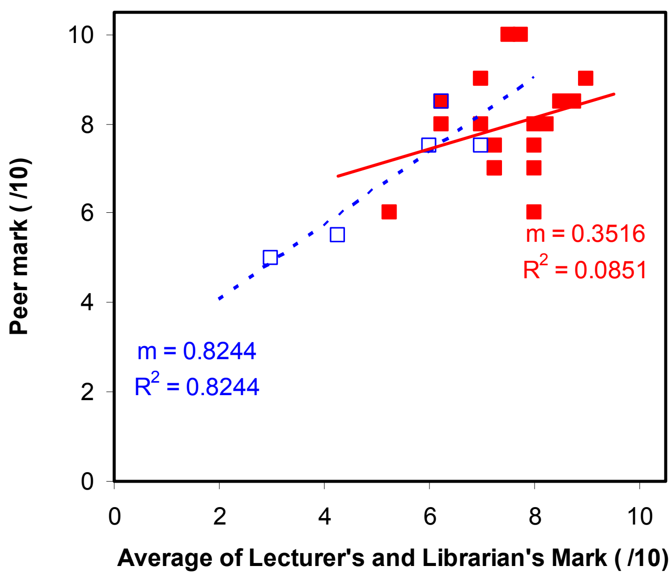

Figure 2: Correlation between peer mark and average of lecturer's and librarian's mark. (symbols as for Figure 1).

Figure 3 shows the correlation between the peer mark and the lecturer's mark for a cohort of postgraduate students. Though the correlation for the native English speakers is strong, the sample is so small that we can say little regarding the trend. For the EFL/ESL students, the correlation is close to zero (R^2 = 0.0004) indicating either or both lack of critical ability is assessing peers work and/or reluctance to criticize another's work. The gradient of the EFL/ESL trendline is close to zero (m=0.0241) with an average close to 8. Most EFL/ESL students adopted the universal mark of about 8/10 for the literature review they marked even though this would reduce the mark they received for their marking effort. We note that the names of peer markers were released to the writers of the literature review.

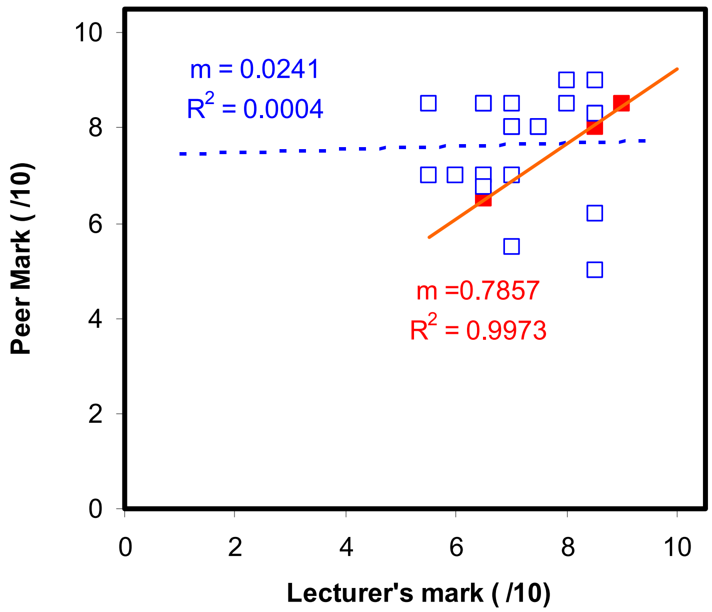

Figure 3: Correlation between peer mark vs. lecturer's mark. (symbols as for Figure 1).

Conclusion

Whilst the majority of students wrote good reviews in the sense they understood the technology, their English expression and writing skills were found wanting. Because of this the academic and librarian had to moderate their respective marks to arrive at a consensus mark. We think the ***creative tension*** in moderating a student marks was instrumental in finding the right balance between students' technical knowledge acquisition and their generic capability improvement.

Significant differences in students' ability to undertake critical evaluation of literature and their peers' work were found to be related to their background and English ability. It may be desirable in the future to specifically target this group to help them develop these skills.

As an action research project we have implemented changes as a result of the findings of the present study which will have ongoing evaluation. The major development is an online teaching resource which has been created to guide students. We have removed student choice in citing styles having stipulated an Author-Year style (and given examples of citing most literature categories). Our online teaching site has links to exemplar review publications in energy and engineering. As an ongoing piece of action research, 2003 students have the benefit of reading our marker's feedback to the 2002 cohort before they undertook their literature review. Evaluation of these measures will be the subject of future papers.

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Information literacy for a sustainable career in engineering and technology

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***Abstract**: Information literacy has become an important skill for undergraduate students due to societal changes that have seen information become a valuable commodity, the need for graduates to become lifelong learners to remain effective across their working lives, and the recognition by many stakeholders that information literacy is an underpinning generic skill for effective learning in higher education. Important elements in the design and delivery of information literacy training include the collaborative process between library and academic staff, the need to link generic information literacy skills into the specific discipline context of the students, and catering for a wide diversity in the student body including off-campus students. This paper describes a sequence of activities designed to help students learn and practice information literacy skills that have been purposefully designed and integrated into a first-year engineering and technology study unit as a core element of the unit syllabus.*

***Keywords**: information literacy, lifelong learning, graduate attributes*

The importance of information literacy

There are many conceptions of what is meant by ‘information literacy’ (Klaus, 2000). The Council of Australian University Librarians has adopted the following definition from the American Library Association, “…an understanding and set of abilities enabling individuals to ‘recognise when information is needed and have the capacity to locate, evaluate, and use effectively the needed information’” (Council of Australian University Librarians, 2001). There are a number of factors that make information literacy an essential skill, particularly for students in higher education.

In many countries there has been (and continues to be) a fundamental change in industry, economy and society from a manufacturing/product basis to a service/information basis. Until the 1960s, Australia’s growth and development was driven by manufacturing (Australian Bureau of Statistics, 2003). However, since that time a combination of economic conditions and structural industry changes have seen new growth dominated by the service industries (Australian Bureau of Statistics, 2003). Such a societal change requires that people be equipped to deal effectively with information as a valuable resource and commodity. Developments in information and communication technologies (ICTs) have had (and will continue to have) a profound impact on modern society and culture. Hence, it can be argued that information literacy is now an underpinning 'liberal art' that students require to not only operate effectively during their undergraduate studies and in their future workplace, but also to play an active and critical role in broader society (Blakeslee, Owens, & Dixon, 2001) (George, McCausland, Wache, & Doskatsch, 2001).

While many commencing engineering students may be regular computer users and may have access to a computer (Palmer & Bray, 2001), many do not have well developed information literacy skills – "Typing on a computer is not word processing and surfing channels on AOL is not information research" (Blakeslee et al., 2001). While having the 'technological literacy' to actually access computer-based information sources may be an important part of information literacy (Burkle & Sayed, 2002), technological competence is not the same as information literacy (Candy, 2000). Mature age students may have prior experience with paper-based access to information, and conventional entry students may be familiar with on-line searches using Google or Yahoo, but both may need assistance to effectively use the new academic information resources offered to them in higher education (Tenopir, 2002).

It is now recognised that if graduates of higher education are to operate effectively over their entire careers, not just immediately post-graduation, then they need to become 'lifelong learners'; "Discipline specific skills in many areas have only a short life, and what will be needed in even the medium-term cannot be predicted with any great precision." (Higher Education Council (Australia), 1992). Lifelong learning includes all formal, informal and occasional learning throughout life (Candy, Crebert, & O'Leary, 1994). Advances in technology, knowledge and society ensure that engineers, as much as any profession, must become lifelong learners to deal with this change. To become lifelong learners as graduates, students need to be appropriately prepared in their undergraduate studies. Many universities have explicitly identified the strategic link between information literacy skills and being an effective lifelong learner post-graduation.

The focus in the last decade on quality assurance and accountability in higher education has lead directly to a focus on the 'outcomes' of higher education, including issues such as graduate employability and graduate attributes (Higher Education Quality Council (UK): Quality Enhancement Group, 1996). The idea of graduate attributes generally encompasses two main types of student achievement; i) the attainment of a discipline- or field-specific body of knowledge; and ii) the attainment of more general, or generic, attributes which might be common to all, or most graduates. Many universities now include information literacy, either explicitly or implicitly, amongst their graduate attributes/outcomes identified in teaching or strategic plans.

In the case of undergraduate engineering education, required graduate attributes are also identified by the professional body that accredits undergraduate engineering programs, the Institution of Engineers, Australia (IEAust). The IEAust course accreditation manual includes the following required 'generic attributes of a graduate' that imply information literacy competency:
"…
- ability to apply knowledge of basic science and engineering fundamentals;…
- ability to undertake problem identification, formulation and solution;…
- expectation of the need to undertake lifelong learning, and capacity to do so." (Institution of Engineers Australia, 1999).

Elements in the delivery of information literacy

Naturally, the library plays a central role in the development and application of information literacy skills for students. However, this role cannot easily be abstracted from the learner's context. This includes both the discipline the student is studying and the mode in which the student's learning is mediated (ie, are they a face-to-face student, are they an off-campus student, are they an on-line student, etc?). It has already been noted that information literacy is an underpinning skill for effective learning, however, in practice, it is often 'integrated' into an existing curriculum or syllabus. This can lead to the simplistic view that it introduces 'extra objectives' into the curriculum and is not a core part of the study unit (Bruce & Candy, 2000). If we accept that information literacy is a key element of professional preparation, then it needs to be considered systematically in curriculum design (George et al., 2001). There are a number of important elements to consider in the design and delivery of information literacy training to undergraduate students.

Collaboration between academic and library staff is essential for the effective planning, development and delivery of training and resources to assist students in the development of information literacy. Information literacy is an essential graduate attribute, and libraries are the principle provider of the relevant discipline knowledge and information resources. However, students normally complete their study in the context of an academic course offered by a faculty or school. Hence both areas must cooperate to deliver these skills to the student (Orr & Wallin, 2001).

If information literacy activities are to be effective, they need to be properly planned; hence the collaboration between academic and library staff needs to commence with the planning of such activities. Library staff can provide input on program guidelines from information literacy professional associations, and academic staff can provide input on the characteristics of the learners and their learning context (Moran, 1998). Once the desired aims and learning outcomes have been identified, the process of achieving them that is suitable for the individual academic situation must be established (Orr & Wallin, 2001).

Generic approaches to information literacy have been reported by students as lacking relevance (Hill & Woodall, 1999; Orr & Wallin, 2001). It is reported that information literacy, while a generic skill, needs to be interpreted and delivered in the context of a student's specific discipline if it is to be effective (George et al., 2001). So, while we may refer to information literacy as a 'generic' skill because of its underpinning support of all study, it is not really a global, context-free attribute of all students irrespective of study discipline. Each discipline has its own unique 'literacies', and even within a discipline 'information literacy' may encompass a range of sources and strategies (Candy, 2000).

Information literacy training delivered when students have an immediate need for it in their studies is likely to find students highly motivated (Fjallbränt, 2000) and/or be most effective in teaching these skills (Hill & Woodall, 1999). Where training focuses on the use of electronic information resources, such training should demonstrate database resources that are appropriate to the students' discipline area (Tenopir, 2002). While the development of generic skills such as information literacy are enhanced by presenting them in a discipline context, it is also suggested that information literacy training must incorporate a balance between cognitive/theoretical and practical skills (Moran & Gibbs, 1999). The most effective learning environment for information literacy development is perhaps not just a discipline context, but also a practical context; activity is important to reinforce theory (Blakeslee et al., 2001).

As the diversity of the undergraduate student population grows, there is a need to consider how information literacy skills training can be effectively designed and delivered to these various student groups (Moran, 1998; Orr & Wallin, 2001). It is recognised that on-line delivery of information literacy training is one way to address the needs of students who cannot attend face-to-face classes, and while off-campus students may the principal beneficiaries of such on-line training, it then becomes available to all students who have access to the on-line learning environment, regardless of their mode of study (McCarthy, 2001).

While on-line resources can offer greater flexibility in the 'place of offer' of information literacy training, another closely related aspect of the increasing 'client focus' in teaching and learning is flexibility in 'time of offer' (McCarthy, 2001). The undergraduate engineering curriculum is notoriously full, and even for on-campus students (and especially for off-campus students) having information literacy training available on-line/on-call for use as required can be helpful (Hill & Woodall, 1999). The move in many areas (including engineering) to project- and problem-based learning means that students may be actively seeking information related to their studies. In this situation however, there is unlikely to be a particular point in time for a formal information literacy exercise that will suit all the students in a given class. In this circumstance, on-line information literacy training can help (Fjallbränt, 2000).

As both course materials and information literacy instruction move on-line, it is possible to provide both direct links from inside on-line course materials to on-line information literacy materials stored elsewhere, or to embed/integrate the on-line information literacy instruction directly into the on-line course materials – examples of both approaches can be found (Hill & Woodall, 1999; McCarthy, 2001; Tenopir, 2002).

The Deakin University engineering and technology program

The Deakin University School of Engineering and Technology offers three-year Bachelor of Technology (BTech), four-year Bachelor of Engineering (BE), Masters and Doctoral engineering programs in flexible delivery mode. The undergraduate programs are delivered in both on-campus and off-campus modes. As noted above, Deakin aims to ensure that its graduates are information literate. The engineering and technology study unit SEB121 Fundamentals of Technology Management is a first-year/first-semester unit that aims to provide an early element of this information literacy training, as part of the transition for students into university study.

In partnership with the School liaison librarian, a range of academic content, student activities and assessment have been incorporated into the unit as core elements, with the aims of:

- exposing and orientating students to the facilities and services offered by, and accessed through, the Deakin University Library ('the Library');
- exposing students to the rationale for, and the practice of, citing their information sources;
- providing general information literacy training;
- providing training and practise in using specific, discipline-relevant, on-line databases;

- encouraging students to become systematic and habitual users of the information sources available to them;
- providing easy access to information sources; and
- catering for the needs of both on- and off-campus students.

The following is an outline of the information literacy elements of SEB121.

Orientation week (or O-week) is the week prior to the commencement of the formal semester. In an O-week presentation to engineering and technology students, the School's liaison librarian addresses the students to provide an overview of the Library services and to invite students to participate in a self-guided Library orientation tour. As part of the tour on-campus students must book a time to attend, navigate themselves around the Library using a printed guide, and complete a short, on-line interactive tutorial on using the Library catalogue. This initial introduction to the Library is considered important, so students are offered a small reward (some stationery items and a voucher for a coffee at a campus restaurant) and a Certificate of Participation on completion of the tour. The interactive tutorial also provides some information that is required to successfully complete the first item of assessment in SEB121. The approach of providing an informal library orientation tour as part of O-week is documented elsewhere (Hill & Woodall, 1999). The self-guided tour remains available for the first two weeks of the semester, so that any students unable to attend in O-week are able to complete it prior to the due date for the first assignment. For off-campus students there are Library orientation resources available on-line which, again, involve the students completing the interactive tutorial on using the Library catalogue, so that they can complete their first assignment.

The course materials presented to both on- and off-campus students cover the issue of quality/validity of reference sources, intellectual property, academic integrity and plagiarism. Students are encouraged to consult the literature to develop their own knowledge in new areas, are exposed to sources of information they can use, are encouraged to use the work of others to support their own propositions, and are required to acknowledge all sources that they consult and incorporate into their work. An important element of this is exposure to, and practise with, systems of referencing, including formats for referencing on-line sources of information.

The third item of assessment for SEB121 requires on-campus students to attend a 'Library Information Literacy Skills Session' where students meet in small groups (no more than 15 at a time) with the School's liaison librarian. This session leads on from the previous self-guided tour (which is generic in content and available to all commencing students), and focuses on information resources specifically for engineering and technology students. The session is held in a computer laboratory inside the Library and the small group size means that students can individually trial their own catalogue, database and web searches during the session. The assessment element of this activity requires students to individually produce a formatted bibliography of references that they could use in the completion of the fourth item of assessment for SEB121 (which is a topical/informative report on any issue relating to engineering/technology). The bibliography produced must contain at least two textbooks, two periodicals and two web sites. This information literacy element is designed to provide a discipline-specific follow-up to the more general self-guided tour, purposefully held physically inside the Library, in a small group situation, with hands-on practise of the theory presented in the session, requiring students to practise different forms of referencing, and completing an exercise that will not only fulfil their immediate assessment requirement, but also directly assist them in the completion of their next assignment.

Off-campus students cannot normally attend this library session in person, but have available to them a comprehensive on-line Library skills/information literacy tutorial known as the Smart Searcher tutorial (Churkovich & Oughtred, 2002). Smart Searcher includes interactive tutorials on the following topics:

- the Deakin Library web site;
- searching using the catalogue;
- performing Keyword catalogue searches;
- understanding your research topic;
- referencing;
- finding journal articles; and
- searching the Internet.

Completion of the tutorials requires students to interactively demonstrate their basic mastery of the tutorial topics above. While the Smart Searcher tutorial is generic in the sense that it is designed for students from any discipline, in the context of the third and fourth assessment tasks, this knowledge is immediately put to practise in the discipline area of the student.

The study unit SEB121 has on-line resources available on the web. Apart from unit-related administration and academic material, an on-line discussion area, etc, direct links are provided to a range of on-line information resources, including:

- the general Library catalogue search page;
- the Keyword Library catalogue search page;
- a Library page of links to on-line resources for engineering and technology;
- a range of relevant, on-line, full-text databases provided by the Library;
- a range of Internet search engines;
- a range of material on the Internet related to SEB121 content; and
- the Smart Searcher on-line tutorial.

These resources are not targeted at a particular student group, and are available for all SEB121 students to use.

It was noted previously that flexibility in 'time of offer' is important – much of the potential 'flexibility' of information literacy resources will be lost if they are only offered at fixed times. The self-guided tour for on-campus students is scheduled multiple times each day during O-week and the first two weeks of the academic semester. The on-campus Library Information Literacy Skills Session is offered ten times over a two-week period during normal SEB121 tutorial times, both to keep the class size small and to permit students as much flexibility as possible in choosing their time to attend. The various on-line resources are available at all times – network permitting.

It is suggested that, "Assessment of information literacy in undergraduate education is essential…for faculty members and students to address the skills required to achieve information literacy" (Catts, 2000). Examples of assessment weightings for engineering information literacy activities can be found in the literature – five percent of a unit grade (Moran & Gibbs, 1999), and eight percent of a unit grade plus a further five percent for a project bibliography (Hill & Woodall, 1999). For SEB121, the self-guided Library tour has no direct assessment value, however, there is a non-grade reward (stationery items and a coffee voucher) and completion of the on-line tutorial element of the tour provides students with information required to successfully complete the first assessment item for the unit. The third item of assessment is a bibliography produced on the basis of attending either the on-campus Library session or completing the off-campus on-line tutorial. This bibliography accounts for five percent of the unit grade, and is linked to the successful completion of the fourth assessment item, which is a topical report worth 15 percent of the unit grade. The aim here is not direct compulsion to complete the information literacy activities for unit marks, but to imply and demonstrate that the information literacy activities have an inherent and pervasive value in the completion of a wide range of learning and assessment activities.

It is planned to conduct a formal evaluation of the information literacy elements of SEB121 in 2003. Approval was sought and received from the Deakin University Human Research Ethics Committee (DUHREC) to conduct an evaluation exercise with the following elements:

1. a formative/qualitative evaluation of the self-guided Library tour – the on-campus session for on-campus students, and the on-line tour for off-campus students;
2. a formative/qualitative evaluation of the information literacy session – the on-campus session for on-campus students, and the Smart Searcher tutorial for off-campus students;
3. a pre-test/post-test evaluation of student knowledge/skills in basic information literacy in recognising common forms of referencing – before and after the information literacy session.

There are examples in the literature of the use of pre-test/post-test competency tests to evaluate the quantitative effectiveness of information literacy training, combined with questions seeking qualitative responses to assess student perceptions of information literacy exercises (Blakeslee et al., 2001; Churkovich & Oughtred, 2002).

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Digging Holes or Building Wholes? Reflections on Teaching Communications

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Abstract: *This paper describes difficulties of teaching a non-technical subject to engineers, in this case, the 2nd Year Communications Subject in Civil and Environmental Engineering at Monash University in Semester 2, 2002. The subject uses a project and personal development format. The authors extended the choice of project to the students, as well as reinforced the notion of professional communications for particular audiences such as clients, managers and the general public.*

The innovation of allowing students to select a project on the basis of their interests and concerns ensured that the students were engaged in the communication tasks. The personal development tasks also engaged the students – although they found this more challenging. Short term interest in marks made it difficult for some students to engage fully in all tasks.

Some thoughts are included on the challenges for the Professional Practice courses in Program Renewal at RMIT. We contend that, for engineering education to be sustainable students and their learning need to become central; we need to focus on the ideas of professional practice and how students can extract the lessons that they need to learn from the resources around them (including lectures and tutorials) and that problem-based methodologies provide a framework for this change of educational practice.

Keywords: *Teaching Innovations; Engineering Education, Communication skills, Graduate capabilities*

Some History

In 1998, the Department of Civil Engineering at Monash University introduced a new civil engineering program (see Hadgraft & Grundy, 1998, for an overview). This new program included a 4-credit point subject called Communications, CIV2203, in the second year, which was first taught in 1999. (This subject existed under other names from as early as 1986). The scope of the subject included written, oral and graphical communication skills, teamwork and problem solving.

The authors taught this subject in 2002 as external consultants to Monash. (The second author taught it during 1999-2001). This paper includes the authors' reflections on the semester's work, as well as lessons to be learned for Program Renewal at RMIT. The paper draws some general conclusions about how to teach subjects such as this in an engineering curriculum.

Focus of Communications Subject

The focus for the Communications subject in Semester 2, 2002 was on the development of non-technical, professional skills, such as oral, visual and written communications, group-work, time management and problem solving within a Civil or Environmental Engineering context. Also, our intention was for the students to consider and use this course to develop further the type of skills that they needed for their career.

The tasks that were to be completed by students were:

- Develop a career plan, which doubles as a first writing exercise
- Develop a job application for vacation work and attend a mock interview
- Form a team to work on a project of mutual interest, including defining the nature of the problem and the attendant project, a progress report and a final project report, as well as oral presentations, brochure, press release, drawings and a web-site
- Debate the project topic with another group
- Reflect on the groupwork experience
- Maintain and submit a logbook of the semester's work

These tasks are listed in Table 1 in more detail, and divided into individual (personal) and group (project) skills, some spanning both areas. Although all tasks had elements of both project and personal development, the project work tended to be more group based whereas, in the personal development, students rarely asked for direct help from others. That is, students didn't realise that they could get their group members to help them improve their writing, for instance. This is a common and essential skill in the workplace.

<table>
<tr><th>Personal Development (individual)</th><th>Project (group based)</th></tr>
<tr><td>Career Plan</td><td>Project Brief – written and oral presentation</td></tr>
<tr><td>Vacation Job Application</td><td>Press Release</td></tr>
<tr><td>Mock Interview</td><td>Brochure</td></tr>
<tr><td colspan="2">Choose project – preferably engineering related</td></tr>
<tr><td colspan="2">Convince others to join your project/Be convinced by others to join their project</td></tr>
<tr><td colspan="2">Working in a group</td></tr>
<tr><td>Reflection on Groupwork – written</td><td>Progress Report – written and oral</td></tr>
<tr><td>Personal Logbook</td><td>Research on project</td></tr>
<tr><td>Debating</td><td>Sketches – relevant to project</td></tr>
<tr><td></td><td>Final Report – written and oral</td></tr>
<tr><td></td><td>Technical Drawing – 2D and 3D (option of using drawing package)</td></tr>
<tr><td colspan="2">Create Project Website – choose design principles from web site – then defend web-site design on basis of design principles.</td></tr>
</table>

Table 1: Assessment Tasks

The subject was designed so that the communications skills were developed through a project and some personal development tasks. These two "threads" merged together through the semester. The students could learn in many dimensions, particularly around the project of interest to the group and how this relates to the profession that they are pursuing – civil or environmental engineering. They were also required to do some personal tasks that helped them focus on their own needs and abilities. Figure 1 portrays this expansion of learning in these dimensions.

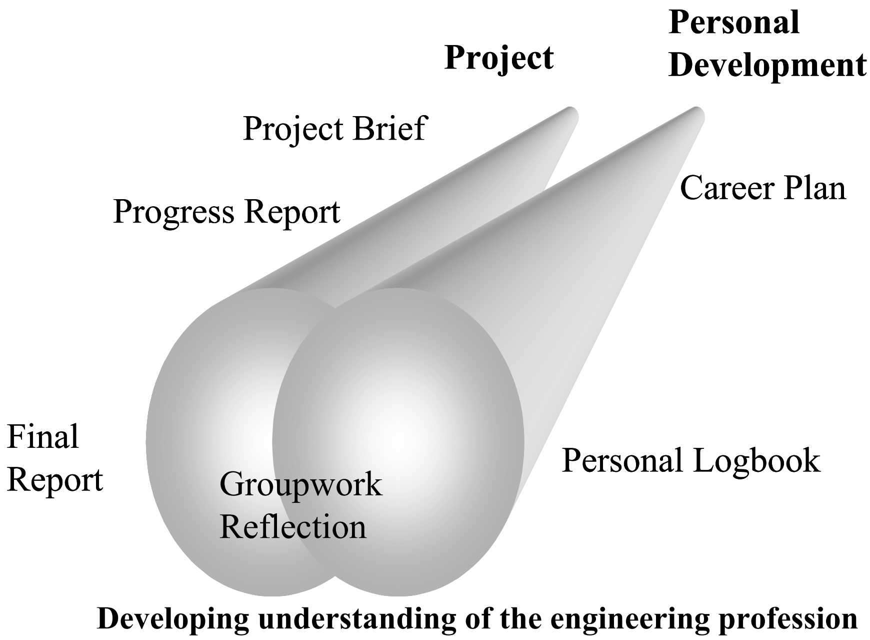

Figure 1: Relationship between tasks and learning over the Semester.

Choosing the Project Topic

In previous instances of this subject, all students attempted the same project, which was assigned to give students some experience of simple design and to allow the generation of some drawings, reports, presentations and teamwork. Previous projects had included student villages and the redesign of the civil engineering teaching spaces to make them more effective learning spaces.

In 2002, the students chose projects based on their own interests and concerns. Our rationale for having students select their own topic was to force students into thinking about and identifying what they really want in their career and in their course. The projects also picked up the objectives of previous instances of this subject - giving students some experience of design and allowing the generation of some drawings, reports, presentations and teamwork

Table 2 lists the projects that were eventually chosen by the students; groups of 2 to 6 students worked together to complete these tasks. This list shows the huge range of interests and concerns of this group of 2nd Year Civil and Environmental Engineering students and the challenge for this subject and the course to keep their interest. All project teams completed all project assessment tasks to a reasonable standard. Some teams produced tangible outcomes outside those requested (for example the Brochure produced by the Environmental Students).

Challenges for Students

Of the tasks listed in Table 1, the most challenging to the students were those in the Personal Development column, as well as, those that span both columns:

- The challenge to students to reflect on their own interests and concerns;
- The relationship between what they needed now and at the same time considering what they would need to develop for their future career was problematic.

At the same time, the Personal Development tasks provided significant breakthroughs in understanding; some students gained a greater understanding of *why* they were doing this engineering course and others understood *why* they should/could be doing another course or going to work!

Brochure – What is Environmental Engineering? For Prospective Students	**The Changing Nature of Engineering**
Survey of Energy Solutions for the Future	Documentary on Engineering
Water quality management and delivery system for a Thai village	Water reticulation for an island in Malaysia
Monorail solutions in Outer Melbourne (1)	Monorail solutions in Outer Melbourne (2)
A traffic management project – Springvale Road	Extended use of CityLink Intelligent Transport System
Noodle Bar at Monash Uni	
Making Melbourne Sustainable	A Sustainable Suburb
Student apartments	A Shopping Centre renovation
World Trade Centre reconstruction	A Hotel Redevelopment
Luna Park Development including Slide	Floating Stadium
Ice Hockey Stadium (1)	Ice Hockey Stadium (2)
Football Stadium Renovation	Building Pyramids Now

Table 2: Project List

Grading

As facilitators of learning (tutors) we discussed saying to students that we would make them all A-grade students if they could justify, in as much detail as possible, why they should be given this extraordinary grade. From Zander & Zander (2000),

> *"grades say little about the work done……..Most would recognise at core that the main purpose of grades is to compare one student against another……….Michelangelo is often quoted as having said that inside every block of stone…dwells a beautiful statue; one need only remove the excess material to reveal the work of art within. If we applied this visionary concept to education, it would be pointless to compare one child to another. Instead, all the energy would be focussed on chipping away at the stone, getting rid of whatever is in the way of each child's developing skills, mastery and self-expression. We call this practice giving an A. It is an enlivening way of approaching people that promises to transform you as well as them……. The practice of giving an A transports your relationships from the world of measurement into the universe of possibility."*

But we decided that the current curriculum and assessment system within which this subject sits did not support this way of viewing learning, so we continued with assessment (gradings and marks) and this became an issue, which we highlight later in this paper.

Some issues with tasks

Choosing a project was problematic for many:
It seems that many students had never been given the opportunity to choose their own focus for their learning. There were concerns about "how big it might be" (either too big or too small) and how complex. There was also difficulty in defining the problem and there was a tendency to choose the solution (eg a monorail) before the problem was identified (inflexible public transport).

Some Asian students in particular found the concept of choosing the "right" project difficult to come to grips with and again Zander (2000) is some help here "In some Asian cultures, a high premium is traditionally put on being right. The teacher is always right, and the best way for students to avoid being wrong is not to say anything at all." Basically, what we were doing by opening up the choice to the students was offering the chance to choose the right (or wrong) project for them – a challenge for students who see the need to be right and expect teachers to make these decisions. But in choosing their career and goals as well as how best to get there, it is not the teacher that makes the choices, but the student. The skill of choosing is essential to living effectively in the world.

Real world practice was seen as too harsh:
Typical industry practice used to categorise job applications is to sort into three groups – those not worth looking at (the BIN category), those that will definitely be short-listed (SHORT-LIST) and those that may be worth looking at further if there are not enough candidates to short-list (RE-CONSIDER). This scheme was used for the students' vacation employment applications and caused great consternation – "you can't do that", "that's not fair" re-sounded around the room. Those applications assessed as in the BIN category were those with no resume, or no letter, or that were unreadable and yet these students could not see that the recipient of such an application would not spare the time and energy to seriously consider it, yet they expected that the tutor would put effort in where they would not.

The reflection tasks:
Both group-work and personal reflection, were difficult and were easily "put-off", particularly with the busy-ness of engineering student life. Our advice at the outset was to document experiences and reflections as the students "went along" in the class (using a logbook) but instead many left this task to the last minute. The evidence of last minute reflection could be seen in very neat notebooks all written with the same pen, in the same format, as well as a high degree of similarity across the reflections.

At the same time there were some huge insights by some students who spent quite some reflective time trying to work through the (long) list of questions – again our advice had been to focus on a few questions that resonate with the student, rather than answering all. Some examples of reflections were - "I don't really know why I'm doing engineering" "I got confidence from giving presentations" " I need to focus more on capturing the audiences attention" "I need to consider more the expectations of the client, the boss and the team when I am communicating" "Debating is more successful when you're prepared, both individually and as a team" "I need to question more" "I need to learn how to compromise and look at things from other peoples' perspectives" "I realised that there are lots of resources available, particularly for learning drawing skills but I need to take the time to use the resources".

Authoritarian leadership models:
Some students felt that they were better at leadership (and even considered themselves to be better students) than others and this resulted in the disintegration of some groups. Rather than deal with the issues involved and to learn from the experience, it was seen to be easier to separate from the group and find more amenable group members.

Group members were not "pulling their weight":
In the final reflections, group members identified others who were not seen to be "pulling their weight"; we had advised that if this was the case at any stage this should be brought to our attention by not including their name on work handed in or by discussing with us at the time. It is very difficult for us to deal with this in retrospect as each piece of work has been marked as we went along. Our advice was to take it up within the group or with the respective individuals – that is, deal with it, as you would do in the work environment, rather than asking others to deal with the issues.

Lack of collaboration:
Even though in some cases there were similar projects (water; stadiums; "what is engineering?"; projects focussed on sustainability, monorails etc) being attempted, these groups did not see each other as possible resources to be used. Again there was an element of competition for Marks being reflected here, rather than the view that you can draw on all the resources available, as in the workplace.

Impractical designs:
Drawings were presented of a floating stadium that had no means of floatation or propulsion, it had no access on and off, no clear idea of where it would be sited and no emergency procedures etc. When the drawings were returned to the students with a low mark, the reflection of the group centred on the quality of the drawing (it was quite well drawn) not it's relevance as a communication tool. This lack of connection with the reality and intent of the project was apparent in other projects also.

Limited use of resources:
The World Trade Centre group focussed on the material they could find on the web. Like the old joke about "the engineer who looks for his keys under the light because that's where he can see", there was little attempt to go beyond this material that was easily available, to seek alternative sources and after significant discussion the group changed tack and reduced the potential of their project.

Some students and particularly many International students would not use the resources available to them, for example spell-checkers and grammar checkers, or get others to proofread the work before handing it in.

Feedback to Students

As well as the reflection directly between tutors and students, either individually or as groups, a detailed (2 page) feedback sheet was provided to all students at the end of the subject. The key recommendations were:

- **Focus on the long-term goal** (your career) and less on the short-term (marks).

- In future project work, **concentrate on learning new skills** and less on getting a good mark. If you concentrate on learning, the marks look after themselves.
- In future subjects, **form groups with a diversity of perspectives** (gender, nationality, age, personality preferences, etc). Learn to listen to other points of view and to respect conflicting opinions and expectations.
- **Use action plans** to guide the completion of the task. These will need to include both short term (this week) and longer term tasks (the whole project), as well as the requirements of the overall course and your life.
- **Use a problem solving methodology** to guide your thinking that is appropriate for the problem. See "The Learning Centre" for one approach and further reading.
- Learn to use several **decision-making tools** to support your decision-making needs.
- **Become an autonomous learner**! Make good use of all the resources around you, including the textbook - Anderson (1999). An effective Internet connection at home will be invaluable during your studies.

Challenges for Staff

Assessment:
The amount of material from around 110 students doing around 20 tasks was large and highly varied in quality. The skill level of the students across the range of tasks was also varied.

There was a commitment to do a good job – to enhance the students' learning in this subject by providing constructive feedback – but at the same time, there was recognition of a limited budget of hours and money and also that for the students this subject was only one among many.

Tutors took the role of the client:
In order to make the tasks as contextually relevant as possible, we attempted to act as per the particular audiences - clients, managers or the general public. We therefore asked questions from the particular audience' perspective and expected to see the material developed with the particular audience clearly in mind.

Large class sizes:
The total number of students was around 110; this meant 4 class sizes of around 26-28. As a result, there was not always time to deal with all the issues that came up and, as a result, we tried to focus on the most important issues (for learning) not necessarily those that were considered by the students as the most pressing/urgent (usually around marks).

Designing the course as we went along:
As we got to know the student groups and where they were up to, we modified the design of the face-to-face sessions and the nature of the tasks to be undertaken. Sometimes this meant that there was different communication to the different groups, which caused great consternation and a flow of e-mails to occur. There was a tendency by students to expect us to be always "on-top" of these issues; our philosophy was that this is often the situation in a work environment where there are different expectations and people (especially the boss or the client) change their minds, and that there is a responsibility on all sides to work through the issues. Learning can occur by dialogue, articulating both intent and expectations, it then becomes easier to understand the many aspects of "why" including both those of the

facilitator and learner – though sometimes it can be difficult to distinguish who is performing which function.

Program Renewal at RMIT

In 2002, the Faculty of Engineering launched its Program Renewal project, to create new programs based around graduate capabilities (eg the IEAust accreditation requirements: IEAust, 1999; also ASCE, 2002). In the current plans, each degree program will include a spine of *professional practice* courses, one per semester. The communications course described above would be typical of what might be taught in either first or second year. What are the lessons to be learned?

The overwhelming impression from teaching CIV2203 and also ENG1601, Engineering Context, in semester 1, 2002, is that, for many students, everything comes down to marks (the short term). "How much is this worth?" is the typical students' response. The semester becomes a sequence of assignments ticked off, but not much real learning happening in many cases. Students failed to grasp the opportunity for:

- New learning (often just sticking to things they're already good at). There was little use made of the wealth of resources at their fingertips (textbook and websites for example).
- Forming groups with non-friends (although random assignment of pairs was used to create some diversity).
- Organisation of group and individual effort (little formal use of action plans or logbooks).
- Formalised problem solving and decision making (these were usually ad hoc).
- Autonomous learning!

The authors believe that fixed agendas with carefully segmented assessment plans lead students to drop into automatic mode, rather than really engaging in the task. Someone else has already decided what is important for each student to learn! The second author has had some success in a fourth year elective in which students worked independently on projects, within a collaborative environment to learn AutoCAD (Hadgraft, 1997). Can this be translated into first and second years with larger, more diverse classes?

Conclusion

Teaching non-technical subjects in an engineering degree is always challenging. Students often see them as a "bludge" or "Mickey Mouse", yet the skills being taught are neither easy to master, nor widespread within the student community. These same skills will be the underpinning of their professional practice throughout their working lives.

It is clear that there is a wide range of capabilities for each skill within the class, together with large numbers in each class. This makes each topic difficult to teach, because many students fail to recognise that they lack the skill (unconsciously incompetent) or they are restless while we cover what they see as secondary school material. It is also clear that marks are a major blocker to *student learning* in non-technical subjects; by focussing on "what is this task worth?" and "what marks do I need to pass?" students are failing to realise their learning potential.

We believe that in technical subjects also, the student' and lecturer' focus on marks-based assessment schemes drives many students' engagement in the course to be "in automatic mode" rather than truly engaging. There is this sense in traditional lecturing that by the student being technically correct, in a fairly narrow way, (e.g. by being able to do the problem set and to get good marks in the exam) that *something will happen* that will allow them to successfully practice in the workplace. In the workplace people expect engineers to practice a whole range of non-technical skills as well as being proficient technically, as well as being able to handle novel situations and problems professionally. Is this not what an engineering degree is or should be preparing students for?

Further some non-technical skills are applied across the technical subjects such as report writing and presentations; these are core also in engineering practice. There is a need for consistent *professional* practices, standards and formats across an academic department for:

- Teams
- Reports
- Presentations
- Use of logbooks or journals
- Explicit problem solving and decision making processes
- Assessment of learning

Students need to see themselves moving from satisfying the teacher (marks) to building their own engineering skills. The development of autonomous learning skills is a key ingredient in this process. To achieve this, a mindset change is necessary. This is difficult in the current situation where a focus on content delivered through lectures turns even active students into passive followers. Substantial changes to teaching practice are necessary if students are to develop themselves to their full potential. Examples of active learning, such as Olin College in the USA, give us hope (Sanoff, 2003).

Returning to the title of the paper, our aim as educators should be to develop whole engineers, not just to dig a number of discipline holes that students fail to connect in their minds. We may be able to make this shift through the subjects of the type described here (Communications for Civil and Environmental Engineers) but then students will need to shift into a different mode for the discipline-based/technical subjects. Some students may be capable of shifting mode but our aim should be to shift all students as quickly as possible to autonomous learners.

On the other hand there may be a case to make a complete shift to problem-based learning methods. A paper (Emery, 1993, pp172 – 175) reflecting on organisational design argues that there is no half-way house in moving from autocracy (where someone outside the work-group – the supervisor, decides what is important) to democratic work groups. Emery shows that the critical thing for democratisation of the workplace is that those that contribute to group performance make the decisions about how they co-ordinate their work; not some supervisor. From our experience, this appears to be relevant to education also - that there is no half-way house between lecturer delivered and autonomous learning. This assertion needs to be validated.

Students and their learning need to become central to engineering education and when we do this we need to focus on the ideas of professional practice and how students can extract the lessons that they need to learn from the resources around them (including lectures and tutorials).

We believe a *more sustainable solution to developing whole engineers* is to shift to using problem-based learning methodology as the core concept. Problem-based learning shifts the *focus of learning* from revealing the types of lessons learned by previous engineers to the students *extracting the lessons they need to learn* for their current and future professional practice.

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An innovative approach to teaching first year programming supported by learning style investigation

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Abstract: *Murdoch University, School of Engineering Science, has since its inception in 1995 been actively embracing new challenges to improve teaching and learning within its courses. One of the aims of the school is to prepare students and empower them for the lifelong learning process.*

Since 1999 the use of Learning Style Inventories to monitor and address student learning has been undertaken, with great student interest and involvement. The importance of understanding the learning process is acknowledged by the inclusion of these surveys in our Engineering 1st year Foundation Unit, a general-purpose unit completed by most engineering students and many non-engineering students. By raising awareness of learning styles students are in a stronger position to take positive control of over their learning.

*Many students struggle with 1st year programming courses and understanding of basic concepts. This research uses **P-Coder**, a CASE tool developed within the school, to aid program design and development in 1st year Java programming units. This innovative approach is being monitored closely by performing pre and post tests throughout the year. Initial results highlight correlations between student learning styles and success in the pre test therefore identifying groups of students who may require additional help. This is a work in progress and tests will be continued at the start and end of each semester.*

If our research can identify students with preferred learning styles as "at risk" then we are in a better position to tailor support material to aid their learning knowledge uptake.

Keywords: CASE tool, learning styles, software engineering

Introduction

Murdoch University, School of Engineering Science, have since its inception in 1995, given a high profile to the role of teaching and learning within its courses. A decision in the early to mid 90s was taken to embrace the new technology of the time. The use of the World Wide Web was in its early stages but it was decided to provide all our courses online. This impacted our attitudes to teaching and learning because at the time this medium was relatively untested. Hence, the initial and ongoing interest in learning initiatives evolved in the school, which has benefited both staff and students. Work was started early in 2000 (Fowler, Allen, Armarego, & Mackenzie, 2000) on using learning style inventories with our students and has rapidly advanced as their usefulness and success was discovered. The two inventories that were researched and chosen were Kolb (Kolb, 1984) and Felder (Soloman & Felder, 1999).

In 2000 the School first offered its own Foundation Unit (McGill, Fowler, & Allen, 2002), which was aimed at providing an innovative and flexible mechanism to assist our students in developing study skills (Rowland, 2001). Murdoch University has several Foundation Units, which are general purpose units, and all first year students must study one of these units. The School decided that this new Foundation unit, *Interactions of Society and Technology,* with its *broad* interdisciplinary nature provided the ideal forum for a component on 'understanding your learning styles' (Fowler, McGill, Armarego, & Allen, 2002). Located on the Rockingham Campus the unit primarily attracts students from the Schools of Engineering Science, Information Technology and Commerce.

This decision affirms the recognition within the School of the value of students' understanding their own learning styles whilst complementing the development of Graduate Attributes (Rowland, 2001) and the Foundation Unit proved to be the best mechanism for developing and highlighting these learning skills within our students. This therefore, supports one of the School's aims to empower our students in their university and life long learning requirements, whilst also providing a mechanism to enable our staff to reflect on their own teaching styles and adopt different strategies where appropriate. The Foundation Unit is valuable for all students but in particular for EngFocus students who have entered an Engineering degree via a bridging course and may not have all the expected prerequisite skills.

EngFocus is an innovative program that had its first run as a pilot study by the then School of Engineering through the December/January period of 2002/03. As a pilot study the program enrolled only 12 students from three local high schools. The program was scheduled for 5 weeks of full-time study with a break over the Christmas/New Year period. This program was designed to provide a bridging structure for non-TEE (Tertiary Education Entrance) students who had expressed interest in studying engineering within the School of Engineering Science. None of the selected students had pre-requisites for entry to University let alone into Engineering Science. Broadly, the students were Year 12 graduates either from a wholly school-assessed background or a strong VET (Vocation Education and Training) educational focus.

The essential idea behind EngFocus was to provide an avenue for non-TEE, VET students to take part in a discipline-specific bridging course that also introduced them to the generic academic skills needed to make a successful transition into University study. These academic skills were in addition to the discipline-specific skills needed to study in the Engineering field. By covering both aspects of their orientation to University the students are exposed to a range of study activities that would be reflective of the learning environment they are likely to engage within the University. The commitment to the students was that they would have the opportunity to experience both the skills and requirements of study within the area of Engineering studies as well as the skills and expectations demanded of them by the University in their first semester of study. This exposure to the breadth of University study was paramount, as the students had not been prepared for academic study through their school experience and, as we did not want to set them up to fail, we had to provide them with appropriate academic experience so that the decision on whether they were going to pursue tertiary study could be made from an informed position.

Both retention issues and the level of learning in first year are of paramount importance for students to succeed. There have been dozens of studies that suggest new techniques as recommended solutions and there have been a few studies that consider the attributes of students that are predictors of success (Goold & Rimmer, 2000) and (Wilson & Shrock, 2001). At Murdoch we are looking to enable students to be flexible in order to achieve success in all environments and have analysed students' learning styles in order to raise student awareness of learning issues (Fowler, Armarego, & Allen, 2001a). We feel supporting first year students in this way is critical to their survival in the early stages of their chosen degree, when they are most at risk.

This research has specifically focused on the use of a software package to help students understand the important concepts required in a first year programming course. By investigating learning styles and relating it to their successes in using our CASE tool, P-Coder, we will be in a better position to aid the students learning process.

P-Coder Case Tool

P-Coder is a CASE tool developed within the School of Engineering Science, by the 4th author, and is aimed as a support tool to assist in the teaching of novice programmers (students taking their first or second units in programming/computing). It is intended for use in relatively small scale programming tasks. It is not intended to be a full-scale development environment, and it will not scale to complex programming tasks. It has not been designed to replace the use of one of the many IDEs that can be used for producing larger and more complex programs.

The teaching of basic programming skills and the underlying knowledge has been a relevant topic for many years. Early interest was sparked in the 1970s with the development of the structured approached, followed by attempts to devise programming languages to support, or compliment, these approaches (e.g. Pascal). Other approaches to programming were also developed at this time (e.g. declarative styles through functional and logic languages). While these have been able to demonstrate considerable strengths in supporting programming tasks, they have not come to dominate the world of software development. Procedural programming concepts have evolved through a range of languages and they provide varying levels of support for the programmer for the programming tasks. In more recent times the evolution of O-O technologies has provided new challenges for teaching.

There is an underlying need to understand the very basic computational processes (sequence, iteration, selection and recursion) no matter what programming language is being used. In modern teaching practice it seems essential that both procedural and O-O concepts are required elements. The challenge is to get the balance right, and, if possible, demonstrate that these concepts form part of a continuum of knowledge that is required by the competent student.

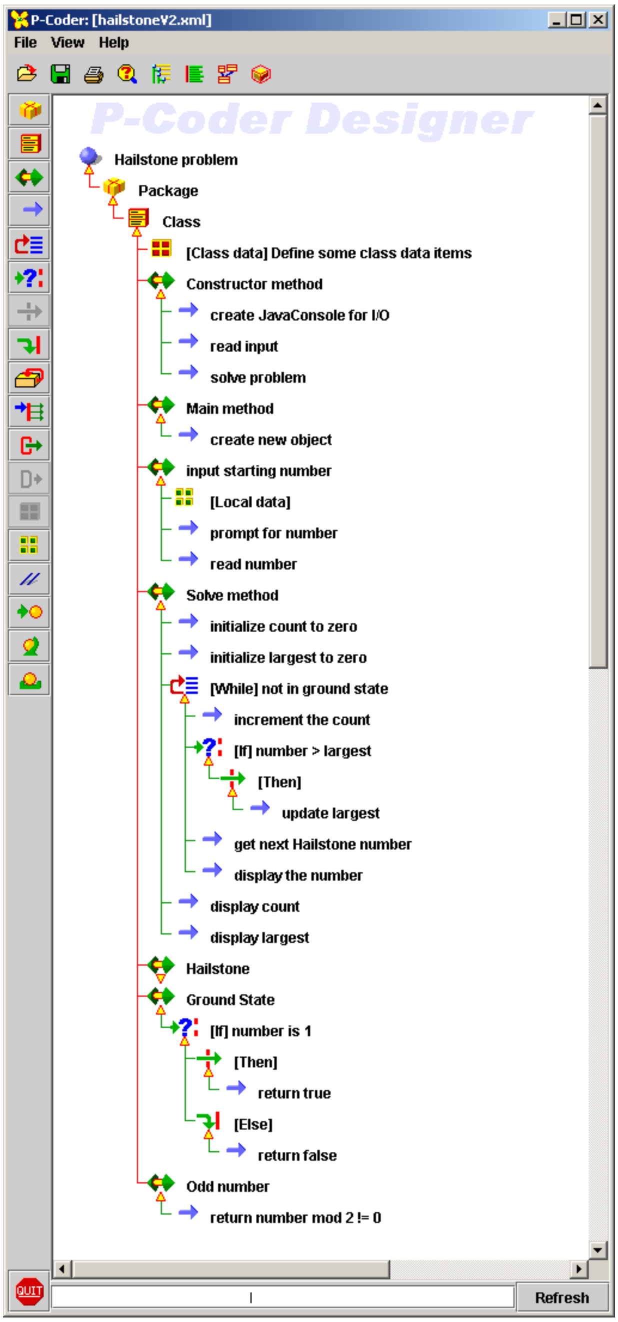

Figure 1: P-Coder Designer View

So, in the 21st century we are still faced with many of the same problems that students faced 20 or 30 years ago. These can be summarised as:

- difficulties in conceptualising the computational task and its solution starting from an informal description of the task,
- confusion between language syntax and the computational process,
- difficulties in devising and understanding the computational algorithm required for the task,

- lack of ability (skill, experience) to understand the flow of computation within a program,
- difficulties in using, and appreciating the advantages of, appropriate encapsulation and modularisation concepts,
- a general lack of understanding of O-O concepts in programming.

In essence we can summarise these by the fact that many novice programmers fail to appreciate the big picture while they struggle with the low level syntactical elements of the programming languages.

P-Coder is intended for use in the early stages of teaching programming skills. It has its origins in pseudocode principles, but also adds some additional O-O concepts that are integral to many modern programming languages. Pseudocode provides an intermediate step in the programming process – a step that can be seen to relate to both the informal specification and also to the final code. In its current form, P-Coder is Java oriented.

The P-Coder CASE tool enables students to design programs using pseudocode and, with additional specification, allows code to be automatically generated. It builds on the four key (and fundamental) computational building blocks (sequence, iteration, selection and recursion) with some added notation that provides other core (especially O-O based, and some Java) concepts to be presented within the framework. The emphasis for the students is now on design rather than syntax. Figure 1 illustrates the designer view within P-Coder, which is used as an entry point for the main programming constructs.

This semester is the first trial run of this innovative tool. After five weeks of the course student response is positive and staff perception is that understanding of important concepts appears to be better than in previous years.

Pre and Post Tests

Since P-Coder was developed at Murdoch it was considered important that an evaluation of the tool be carried out. Evaluation is important in order to clarify whether the technology enhances the student's understanding (Alstrum et al., 1996).

In order to assess the value and success of P-Coder and to monitor student learning, a multi-choice forty question online test has been developed. The test is a formative assessment since it is expected to assist students in the learning process. However, the main purpose of the test is to find out what students know, so it could be described as summative (Isaacs, 1994). The decision to create a test rather than use the standard assessment of assignments and exams allowed a quasi-experimental approach to be taken in this evaluation. Ethical considerations prevented the use of a control group.

This test includes questions covering the entire year's syllabus taught over two semesters. The same test is to be administered four times throughout the year namely week 2 semester 1, week 13 semester 1 (last week of semester), week 1 semester 2 and week 13 semester 2. The aims of the test are:

- to assess student learning,
- to motivate students to increase their score,
- to act as a pre and post assessment of the course.

The students are aware that the scores for the test are not used formally and are purely for self-assessment and research. However the first test has already shown increased student motivation, in that one student commented, "I have read the first five weeks of the course book ready for the test".

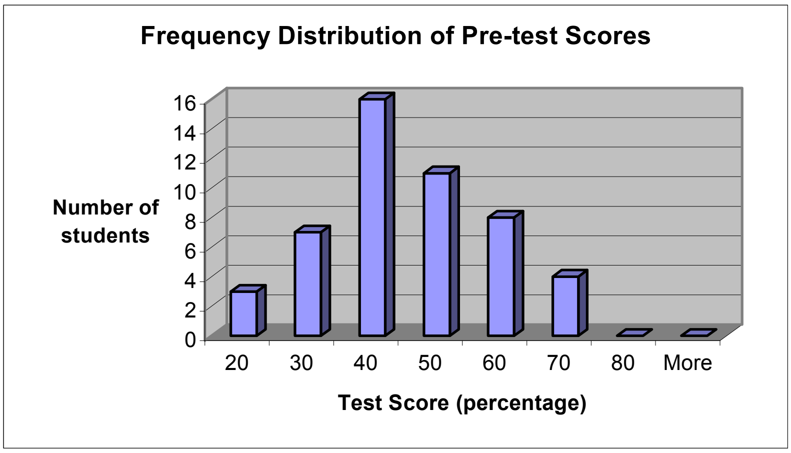

Figure 2: Frequency distribution of Pre-test scores

Results of the first administered test, week 2, semester 1(March 2003) were surprisingly good with an average of 40.8% and standard deviation of 12.6. However the test could not be done before the students had access to the computer labs and so was not carried out until week 2. In addition students were allowed to guess and no penalties were given for wrong answers. It has been shown that guessing is often of a greater benefit to able rather than less able students (Hutchinson, 1991). Although we are unable to prove this, a reduced standard deviation in later tests would be indicative. Figure 2 shows the distribution of scores, which will be compared to later tests.

Learning Style Inventories

Whilst there are numerous instruments for assessing learning styles, those advocated by Kolb, *Learning Style Inventory* (Kolb, 1984) and Soloman and Felder, *Index of Learning Styles* (Soloman & Felder, 1999) are well known, and accepted within education theory (Montgomery, 1995). Both instruments provide an efficient way of analysing our students' learning styles and complement each other on the information they supply.

The learning style inventories evaluate the way a person learns and how they deal with day-to-day situations in their life. Helping a person to understand how they learn and how individuals differ enables them to take positive control over their learning processes. It follows that individuals can be aware of and address the divergences between student and staff learning styles, and academic staff can use this awareness to develop material and teach in a greater variety of ways.

The importance of learning styles and their support on the construction of knowledge is therefore of paramount importance. The constructivist approach (Phillips, 1995) used in this research has focussed on the styles of learning that apply to either different categories of learners, or the learning of different categories of material, providing insights into individual differences in learning and performance. The challenge is to identify the successful mental modelling strategies of the learner or to modify the learner's approaches to learning (McLoughlin, 1996).

Constructivist learning is described by Ernst von Glasersfeld's basic principles:

- that is knowledge is not passively received either through the senses or by way of communication, but is actively built up by the cognising subject,
- the function of cognition is adaptive and serves the subject's organization of the experiential world, not the discovery of an objective ontological reality.

(Heylighen, 1997)

Knowledge can be viewed as a constructed entity made by each learner, through a learning process and cannot be transmitted from person to person but needs to be constructed, possibly re-constructed, by each person. We acknowledge the two major views within the constructivist school of learning: cognitive oriented theories, stressing exploration and discovery, and socially oriented theories, emphasising collaboratory efforts of groups of learners.

Therefore looking at students learning styles to aid the learning process and the construction of knowledge is important. Also, raising students' awareness of issues surrounding their learning will lead to more effective learning practices and study outcomes.

Kolb Learning Styles Inventory

Kolb defines learning styles as one's preferred methods for perceiving and processing information (Jonassen & Grabowski, 1993). He views the learning process as a four-stage cycle: concrete experience (CE), feeling, followed by reflective observation (RO), watching, abstract conceptualization (AC), thinking, and active experimentation (AE), doing. CE and AC represent one continuum, how one prefers to perceive the environment or grasp experiences of the world. The second continuum, RO and AE represent how one prefers to process or transform information. By crossing the two continua, Kolb differentiates four types of learning: *divergers*, *assimilators*, *convergers* and *accommodators*.

The users' learning style, (Burns, 1989), can then be identified as either:

- Accommodator: *What if?* people. Often start with what they see and feel then plunge in and seek hidden possibilities. They learn by trial and error, and self-discovery,
- Diverger : *Why or why not?* These people study life as it is and reflect on it to seek meaning. They learn by being involved and need to listen and share with others,
- Converger: *How?* These people start with an idea and try it out, they like to find out how things work and learn by testing theories,
- Assimilator: *What?* people. These people come up with ideas and then reflect on them. They like to know what the experts think.

Our results build upon our previous studies (Fowler et al., 2001a), (Fowler, Armarego, & Allen, 2001b) and (Fowler et al., 2002) . The learning styles of our engineering students are diverse, and span all categories, (Table 1), indicating the variety of student types that our courses attract. This result is excellent given the multi-disciplinary nature of our curriculum content but we need to be able to cater for all students and their learning styles. Our staff show a greater tendency to be *assimilator* and *converger* types; this is in line with Kolb

(Kolb, 1984) stating that engineering is a good career area for *convergers* and that teaching suits *assimilators.*

Clients	No. of Clients	Accommodator	Diverger	Assimilator	Converger
Engineering 1st year Students	126	8%	18%	33%	41%
Engineering Staff	12	0%	17%	41.5%	41.5%
General Arts & Commerce 1st year Students	198	13%	13%	47%	27%
Year 12 all students	112	26%	10%	44%	20%
Computer Science, IT 1st year Students	66	5%	12%	56%	27%
G108 1st years 2003 only	**48**	**4%**	**8%**	**42%**	**46%**
4th year Engineering students	29	3%	7%	40%	52%

Table 1: Kolb *Learning Style Inventory* 1999 – 2003 cumulative results

Soloman and Felder Index of Learning Styles

The *Index of Learning Styles* (Soloman & Felder, 1999) is an instrument to assess learning preferences on four dimensions; *active/reflective*, *sensing/intuitive*, *visual/verbal*, and *sequential/global*. This instrument consists of forty-four simple questions each with a choice between two possible answers.

The results from Table 2 show the following mismatches between staff and students:

- in nearly all categories students are more *active* than *reflective* but our teachers are mainly *reflective.* The exception is Computer Science/IT and G108 programming students who are showing a more balance split,
- over 59 % of all students are *sensors*, yet our teachers tend to be *intuitive*,
- both staff and students show a heavy tendency to be *visual*, yet traditionally material is presented to them verbally or in written form,
- students show a slight tendency to be *sequential* learners but an increasing percentage are *global* learners, yet teaching is often narrowly focused.

Our results for students are similar to those of Mackenzie, (Mackenzie, 1998), who surveyed 75 Mechanical Engineering students.

The profile of the General Arts and Commerce students has been included for comparison in Table 1 and Table 2. The Kolb survey, (Table 1), has differentiated more clearly between the learning styles of these two groups. The greater tendency towards *assimilators* for the general arts students is consistent with Kolb's description of *assimilators*, as being less practical and more creative.

Clients	No of Clients	Processing	Perception	Input	Understanding
Engineering 1st year Students	126	Active 56% Reflective 44%	Sensory 63% Intuitive 37%	Visual 77% Verbal 23%	Sequential 56% Global 44%
Engineering Staff	11	Active 27% Reflective 73%	Sensory 36% Intuitive 64%	Visual 73% Verbal 27%	Sequential 45% Global 55%
General Arts and Commerce 1st year Students	200	Active 65% Reflective 35%	Sensory 68% Intuitive 32%	Visual 76% Verbal 24%	Sequential 54% Global 46%
Year 12 all students	111	Active 59% Reflective 41%	Sensory 59% Intuitive 41%	Visual 77% Verbal 23%	Sequential 56% Global 44%
Computer Science/IT 1st year Students	63	Active 49% Reflective 51%	Sensory 70% Intuitive 30%	Visual 84% Verbal 16%	Sequential 68% Global 32%
G108 1st year 2003 only	**33**	**Active 48%** **Reflective 52%**	**Sensory 63%** **Intuitive 37%**	**Visual 79%** **Verbal 21%**	**Sequential 48%** **Global 52%**
4th year Engineering students	29	Active 76% Reflective 24%	Sensory 55% Intuitive 45%	Visual 86% Verbal 14%	Sequential 59% Global 41%

Table 2: Soloman and Felder *Index of Learning Style* Survey 1999-2003 cumulative results

Practical applications of our learning styles results are discussed in a previous paper (Fowler et al., 2001a). A suggestion (Felder, 1993) is to talk to students about their learning styles and the strengths and weaknesses associated with each style. We achieve this by incorporating a topic into our first year Foundation Unit to survey and discuss student learning styles.

A potential mismatch between the teaching styles of the staff and the learning style of students is highlighted in both Table 1 and Table 2. Students whose learning styles are compatible with the teaching style adopted within a course tend to retain information better, obtain better grades and maintain a greater interest in the course (Felder, 1993). Yet the diversity of learning styles in our students suggests that flexibility in teaching style is of considerable importance.

Analysis of Results

The relationship between the test results and preferred learning styles of our first-year students, in the G108 programming unit (using P-Coder), will be continued throughout the year as the tests are completed. Thomas et al (Thomas, Ratcliffe, Woodbury, & Jarman, 2002) in a similar study correlated assignment and exam results with Felder's learning style and showed that reflective students scored higher than active students and verbal students scored higher than visual students. This was in keeping with the notion (Felder, 1996) that engineering education is biased towards reflective, intuitive, verbal and sequential learners.

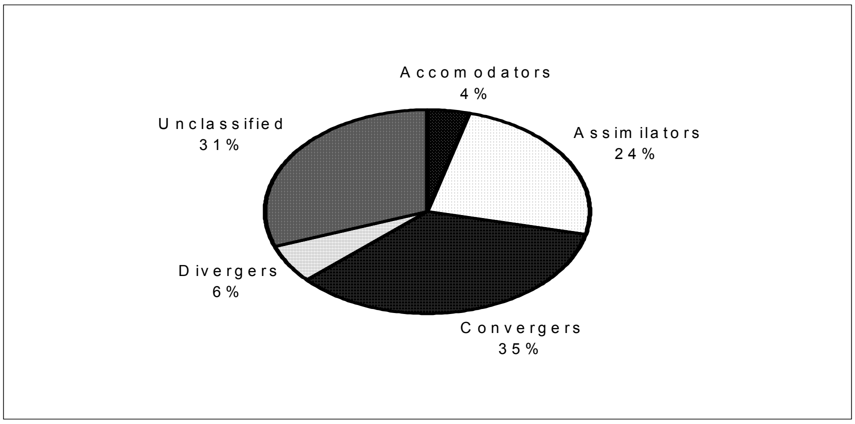

Figure 3: Kolb Learning Styles of 2003 Programming Students – Unit G108

Of the students that took the pre-test on programming, we have so far been able to trace the preferred learning style of three quarters of them, Figures 3 & 4. Of those that have been classified in our sample, *Convergers* and *Assimilators* are in far greater proportion than the very few *Accomodators* and *Divergers.* The scores were higher for intuitive learners, slightly higher for verbal and sequential learners whereas there was no differentiation between active/reflective learners. The correlation between learning style preferences and test scores will be investigated further as results become available.

The average scores of the four learning style groups are shown in Figure 5. Also shown is the mean for students for whom we have no preferred learning style information. While the *Accomodators* and *Divergers* were very small groups when compared to the other three their mean scores do appear to be significantly lower.

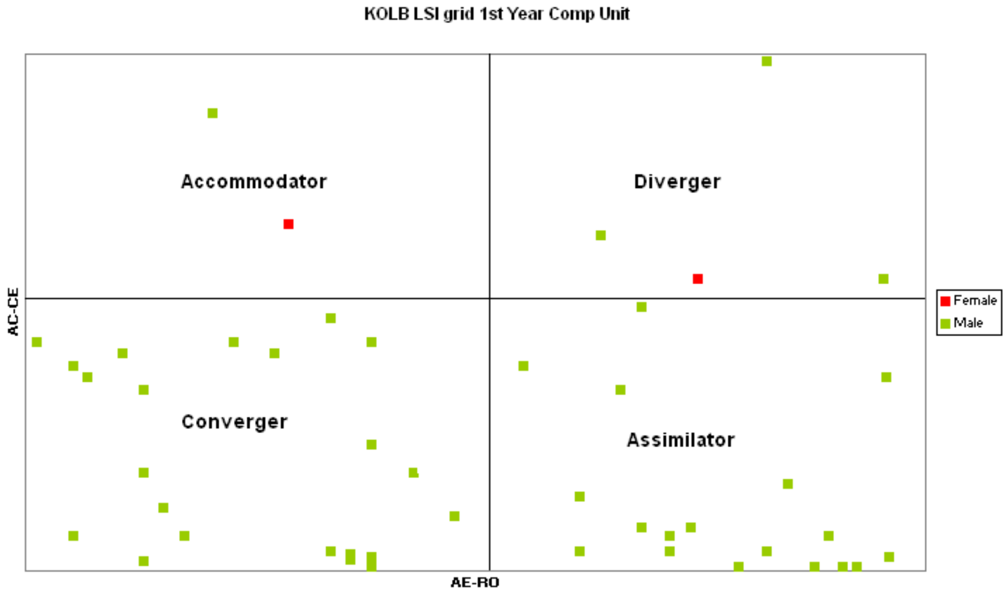

Figure 4: Kolb Learning Styles distribution for 2003 Programming Students – Unit G108/G109

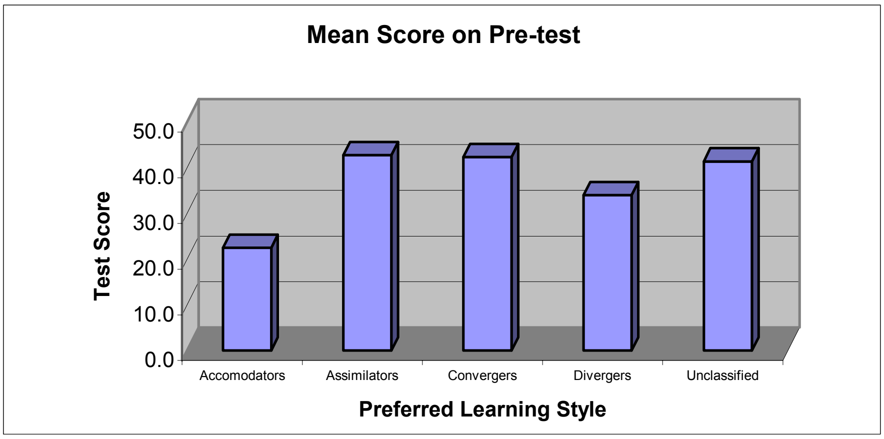

Figure 5: Mean Score for each of the Kolb Preferred Learning Styles

Conclusions

It has been shown in previous years that the *Accomodators* and *Divergers* have not been retained in our student cohort by fourth year. It may be that these students have failed because they are not able to learn in an environment where the teaching style favours *Assimilators* and *Convergers* or that they have modified their learning style to succeed. We feel by following this study through to completion by the end of this year we will have a better idea of which students succeed and therefore be in a better position to adjust our teaching styles to aid those who struggle with basic programming.

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Acknowledgements

P-Coder is a CASE tool that has been developed by Professor Geoff Roy, Murdoch University, School of Engineering Science.

Student difficulties in structural distillation tasks

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Abstract: *One of the key tasks to be undertaken when attempting the mathematical analysis of an engineering system is to construct a model of the system. The model would normally contain elements that correspond to established concepts, for which analytical techniques are available. We use the term 'structural distillation' to describe the activity of identifying the established concepts within the 'real' engineering system. Although we might expect an undergraduate engineering course to develop skill in the act of performing structural distillations, either as a step towards predicting the behaviour of actual systems or during preparations to design systems, this does not appear to be the case. In the very fundamental task of constructing free body diagrams, we found that students in two major engineering courses were significantly deficient in the skill, even though their performance in conventional preparatory studies appeared to be satisfactory. We concluded that the nature of the teaching and assessment tasks in those preparatory studies developed a narrow technique for this aspect of structural distillation that was not transferable to a slightly different type of problem in which the structural elements had less defined characteristics or were visually complex.*

Keywords: *Modelling, structural distillation, misconceptions, visualisation*

Introduction

A fairly typical activity for an experienced engineer might be described thus: an engineering system exists, in hardware, sketch, flowchart, or in the mind, and the immediate task is manipulate the system or its conceptual form so that its embodiment will match the myriad of specifications that have been laid down for the system.

The specifications take numeric forms (Lewis and Samuel, 1989), and relate to characteristics of the solution that can be measured, and usually predicted from the body of knowledge associated with the task scenario. This body of knowledge may be very broad, and include disciplines such as economics, psychology, sociology, law, aesthetics and the natural sciences. Within the concept are alternatives: dimensions, materials and components that separately influence one or more of the specifications in a matrix of interactions (Alexander, 1963). The engineer's task is therefore complex (Lewis *et a*l, 2000), and various strategies are applied to work efficiently towards a final solution.

Crucial to progress towards a solution is an ability to predict the effects of various decisions: is it more, or less likely that the constraints imposed by the specifications will be satisfied? The ability to predict the effects with a degree of certainty requires the use of abstract models, whose validities have been confirmed (or whose predictive accuracy is well known). The engineer must therefore translate the hardware or concept into the jargon of the appropriate abstract models, select data for those models, and then manipulate the enhanced models if they are to predict the degree of match with the specifications.

We call the process of transforming the concept into its models that of 'structural distillation' (Samuel and Weir, 1999).

However, models are imperfect – or more accurately, models are likely to be 'correct' for idealised concepts that are similar to, but not the same as the concept under consideration. The engineer might have a choice between various alternative models that may be more, or less likely to predict accurately in their non-ideal application. The engineer has access to safety factors, their own experience and perhaps intuition (Field, 1994) to resolve these issues.

We are interested in the mechanism by which an engineer gains the skill needed to distil system concepts. A young undergraduate is not likely to possess the ability as a natural skill. How does their training develop their abilities? This paper reports our investigations at two Australian Universities, where we found that one of the most fundamental of modelling skills used in mechanical engineering, that of constructing free body diagrams, was not well developed through conventional courses in statics.

Study Programmes

The research reported in this paper drew upon tests with two groups of level 2 undergraduate students. The first group, at the University of Melbourne (UoM), were enrolled in the level 2 subjects "Engineering design and materials" and "Mechatronics design and laboratory". The second group, at Monash University (MU), were enrolled in the level 2 subject "Design process".

The principles of static equilibrium were contained in very different level 1 studies at the respective universities. At the UoM, the principles were presented as a large portion of a dedicated subject "Engineering mechanics and materials" delivered by staff from the Department of Mechanical and Manufacturing Engineering. The subject was one of four that constituted a full workload during the first semester. The recommended text was the widely used "Engineering Mechanics: Statics" (Meriam and Kraige, 1998), and the subject covered 2-D and 3-D equilibrium, in vectorial and graphical modes. Figure 1 shows sample problems from this subject.

At MU, statics forms a small part of an introductory unit "Civil Engineering" (delivered by staff from the Department of Civil Engineering) which is one of six units that constitute a semester of full time study. The elements of statics are primarily 2-D, and are applied to classical civil engineering forms: beams and trusses. There is no exposure to forces in mechanisms, and the modes of solution are principally through the use of orthogonal components. Figure 2 shows typical problems in statics from this unit. The mechanics portion of a study in Physics at MU contains some elements of FBDs. Figure 3 shows two examination problems from this unit.

A common characteristic of the problem types from both universities is the presence (or strongly implied presence) of external loading, with defined directions and loads (including the cases of gravity loads). The positions of equilibrating forces, or the presence of the equilibrating moments are also quite unambiguous in most instances. Consequently, all the problems covered at both universities have unique, numerical (or algebraic) solutions. This is not unlike problems set in the early levels for most of the other engineering sciences at the two universities.

Draw free body diagrams for each of the structures shown below

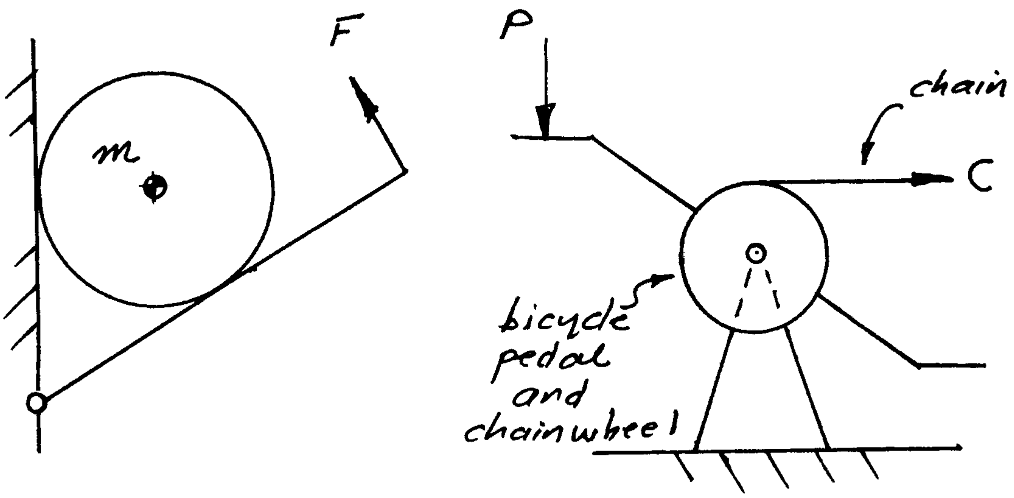


Figure 1: Statics problems used in Mechanical Engineering at the University of Melbourne

(b) Calculate the **support reactions** and forces in the **members** of both trusses subject to a horizontal force of 20 kN. Length of all members = 4m. Indicate whether the members are in tension or compression. (80%)

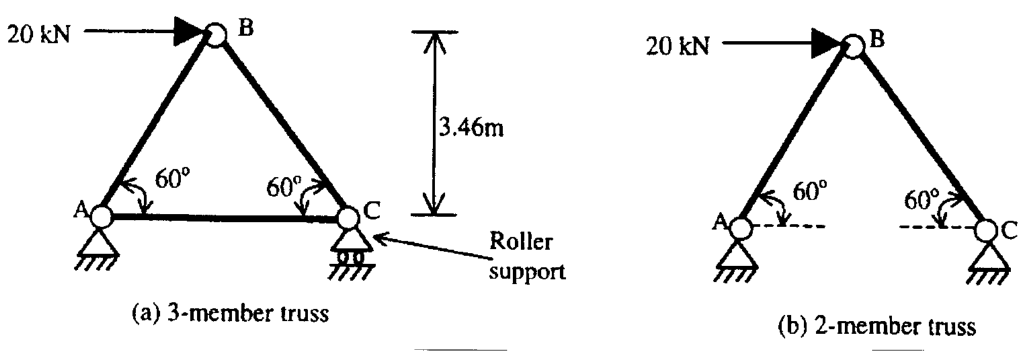
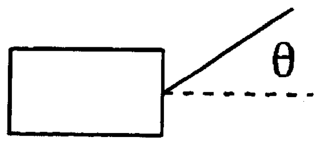


Figure 2: Statics problems used in Civil Engineering at Monash University

The level 2 engineering design studies at the two universities encompass the design of mechanical elements, principally to resist failure, and mainly to avoid excessive stress or deflection. Consequently, an appreciation of the forces imposed on mechanical elements is a prerequisite for the satisfactory design of such elements. However, when design problems are presented in a practical context, it is not uncommon for the task to be defined in words (such as the statement of a need), for which the magnitude, location, and other aspects of loads are variables in the task, to be found, assumed or calculated. Therefore the equilibrium models presented to students in design problems are likely to be relatively incomplete compared with those set in classic studies of statics, mechanics and physics.

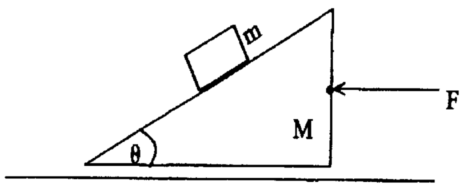
The uniformly poor performance of undergraduate students in the construction of FBDs in level 2 design subjects at both universities, even following the apparently large difference in attention paid to the skill at each university led the authors to investigate the likely causes for the shortcomings.

A 200-N box, which is being pulled with a rope at an angle θ relative to the horizontal, moves horizontally at a constant velocity. The tension in the rope is 35 N and the force of kinetic friction on the box is 20N



(a) Draw a free-body diagram for the box. Label each arrow with the name of the force.

A small block of mass m rests on the sloping side of a triangular block on mass M, and the triangular block itself is in contact with a horizontal table, as shown in the diagram. All surfaces may be assumed frictionless. A horizontal force F is applied to the block of mass M, and its magnitude is such that the block of mass m does not move on the incline.



On the diagram above, mark and label appropriately the two forces acting on the block of mass m.

Using two directions at right angles, write the equations of motion for the block of mass m.

Figure 3: Mechanics problems used in Physics at Monash University

Research Methodology

Similar testing environments were created at each of the two universities, where short 'tests' worth one or two percentage points (to motivate students to seek a correct solution) were conducted during regular weekly lectures. There were seven different tests used in the first half of 2002.

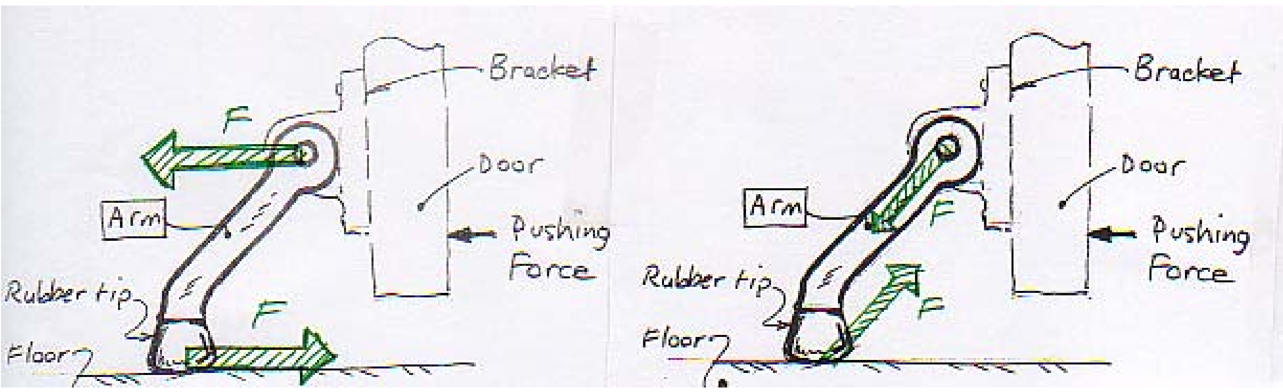
The majority of the tests contained drawings to represent real, familiar artifacts (a doorstop, a spanner, etc.) but which were devoid of the forces or moments that normally act upon those artifacts. Students were to place the forces and/or moments on those images to represent the equilibrium arrangement: no magnitudes of any forces or moments were required. Some other tests represented abstract structures or mechanisms that contained forces (symbolic or numerical), and students were required to find forces at other points in the device.

In all cases, students were only allowed five to ten minutes to reach a solution. They were informed that this small amount of time should have been sufficient to reach each solution (and this was normally confirmed after each test when they were presented with correct solutions).

There were approximately 120 students at MU and 180 at UoM in 2002. Following each test, the papers were assessed by the first author, and those students obtaining a correct solution were awarded their one or two percentage points. It is notable that no test yielded a success rate above 5% at either university. The test papers were grouped into categories of similar or identical solutions, and the most common solutions were identified.

Outcomes

The first problem depicted a doorstop in its functional mode (Fig 4). The task required students to place force arrows on the diagram (or a separate image of the arm portion) to represent the equilibrium of the arm. Single forces acting at any one point were required. The most common solution, offered by 20% of the students at MU, and 15% of those at UoM (Figure 4a) shows a pair of forces that could satisfy the requirement for a zero nett force, but which clearly fails to satisfy the requirement for zero nett moment. The second most common solution at MU (10% of the students) was similar to Figure 4a, but also included a vertical force at the point of contact with the floor. This solution violates both force and moment conditions for equilibrium, and, significantly, violates the requirement to depict a single force acting at any one point. The same problem presented to the 2003 undergraduate cohort yielded the most common solution shown in Figure 4b, with 28% of the MU students and 20% of the UoM students presenting a solution in which the force at the pin is depicted as passing along the centreline of the arm. On this occasion the UoM undergraduates were more successful, with 10% of the group creating the correct solution.

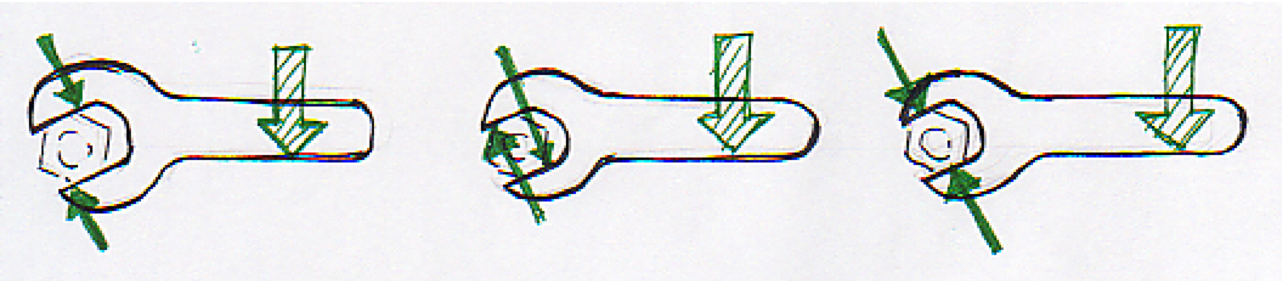


(a) (b)

Figure 4: Common incorrect solutions to a FBD problem depicting a doorstop

A second problem involving the same doorstop image was presented a few weeks later. In this problem, the task was to represent the forces on the bracket. This was a three-force equilibrium task, with the special feature that two of the forces arise from the surface contact between the bracket, its retaining screws (which were described as being loose) and the door. Again only a few percent of the students at each university constructed a satisfactory solution, with most depicting a door reaction force horizontally through the pivot pin.

The problem which asked for the placement of forces on a spanner was also poorly solved. Apart from the non-concurrency of forces and non-zero sum of the forces, many students at both universities created solutions like Figure 5a and 5b. In 5a the contact forces were depicted as acting onto the nut, and in 5b the forces were placed onto the incorrect corner. A large number of students also created solutions like that in Figure 5c (with point or distributed forces), representing a clamp.



(a) (b) (c)

Figure 5: Common incorrect solutions to a FBD problem depicting a spanner

Discussion

None of the seven problems attempted by level 2 students in 2002 involved the application of principles that they had not studied in 2001, during subjects that were prerequisites for level 2 design studies. However, the vast majority of the students at both universities were uniformly incapable of achieving correct solutions to the problems under the conditions that were imposed. While the students at UoM performed a few percent better than the students at MU, the differences were not significant. The authors have considered four plausible reasons for the poor performances.

1. For problems in which no, or only some of the loads were depicted, students required additional insight to locate points of application of the forces, and then to align those forces appropriately. These constituted new, untaught and untested skills. The insight required was largely visual and in some cases (such as with the spanner) required a kinetic mental image of function. Visual capabilities are also required to avoid the misleading clues presented by structural elements that are not aligned with the loads (such as the 'bent' doorstop arm which has encouraged the placement of forces along the 'neutral axis' of the arm in Figure 4b). The authors have for some time been concerned that the general demise in visual/graphic skill in undergraduates may have been partly responsible for a decline in other skills (Field et al, 2001). The results of the experiment are consistent with this hypothesis. Other researchers have noted the tendency for novice engineers to seek more concrete spatial representations during problem solving when compared to their seniors (Ahmed et al (2003), Gobert (1999)), suggesting that shortcomings in visual skill may diminish in later years of an engineer's career. However, the engineers' education may well be impaired by this factor.

2. The tendency for many lecturers to present the analysis of equilibrium problems solely by computational methods encourages the use of force components, rather than whole forces. The introductory studies at the UoM are presented in parallel with vectorial techniques (including the use of orthogonal unit vectors), and at MU with algebraic components to be used when analysing trusses via the 'method of sections' (force polygons are not discussed) and in Physics. Consequently, forces are 'seen' by their components, and in particular in their 'active' components. As a result, solutions like that in figure 4a show the force components that stop the door from closing, and in Figure 5a the forces are those that do the ‘work’: from the hand to the spanner and the spanner to the nut. The very common tendency for students to depict force *components* at a point (like the version of Figure 4a referred to earlier), even though they were instructed not to do so may also mean that they see the components as separate forces (apparently friction and normal reaction are seen as two distinct forces rather than as the components of a single contact force). However, although students universally agreed that they were well aware of the principles that determined equilibrium in 2-D mechanisms, the majority of their solutions, whether using components or whole forces, could not represent equilibrium conditions. Their earlier understanding could not be *transferred* to the new problems. This type of difficulty has long been recognized by educational psychologists (White and Gunstone, 1981).

3. The problems were presented as five-minute tasks, whereas in the past, whole problems in equilibrium were met as substantial activities (taking some 30 minutes or so) in examinations and tests. This change may have forced students to adopt different strategies, when they realised that their previously successful approach may not lead them to a timely solution. It seems likely that the methodological approach of setting up component forces, making separate summations of forces and moments and solving simultaneous equations (without requiring any substantial insight) was now seen as inappropriate, and students may have fallen back onto their intuitive understanding of equilibrium. Therefore their solutions may represent their first thoughts on the solution (which could well become modified if they had been given more time), which shows that student understanding of the principles of equilibrium are either not well understood, or are perceived as a very complex set of rules: too complex to handle in the five-minutes available to them. Perhaps many students have formed misconceptions that are normally masked by the self-correcting mathematics that uncover many of their inconsistencies (such as when they subsequently find that the forces on the flats of a spanner, Figure 5a, are negative). The authors have observed this phenomenon during their study of engineering intuition where students appeared to select diametrally opposite solutions from non-computational choices (Field et al, 2001). In these instances the incorrect choice appeared (visually and psychologically) to be more attractive than the correct solution.

4. At least five months (and in some cases ten months) had elapsed since the students had formally studied equilibrium during their level 1 subjects. We are aware of the great difficulty that students appear to have in applying learning from one subject to another, even from one subject to a following subject of the same name! The 'compartmentalisation' of knowledge and the subsequent mental barriers to accessing that knowledge appear to inhibit the effective application of prerequisite skills. It is also possible that the techniques used in teaching and assessing skills and knowledge do not ensure that concepts are properly understood. Students admit to using past examination papers to help them study for the present examination (one of the problems

in Figure 3 actually appeared in two examination papers two years apart) and appear to look for patterns in solutions that they can memorise and recall, rather than the fundamentals that they can understand and apply. Consequently, those pattern-recognition strategies may only exist in short term memory, and be unavailable in the following years. This phenomenon was also reported by Field et al (1989) during their attempt to use *mastery learning* to re-emphasise first-level topics in a second-level study: many students required three attempts at mastery learning tasks before they could create correct solutions. The observations are instances of surface learning, whereas teachers generally aim for deep learning outcomes (Ramsden, 1992).

Conclusion

Students at UoM had formally studied the graphical and algebraic methods of solving statically determinate problems involving FBDs in the year prior to the experiment. The types of problem in that study involved representations of objects that could have been interpreted as 'real', but were always line representations, and usually partial representations, in that they showed only the portion of the mechanical system that was of interest. Points of application of forces were always shown or implied, while lines of action of the forces were either shown, or implied, or were dependent on other forces. The study, taught by mechanical engineers, was similar to equivalent courses and subjects at other universities, where the nature of problems set by the teacher always led to single 'correct' solutions.

However, during the experiment, it was found that very few (<5%) of the students could apply this knowledge to realistic representations of simple objects where points of application, and directions of forces were not pre-defined, even where there were unique solutions.

Similar students at MU did not have the benefit of an extensive earlier study in which they might have learned how to construct FBDs. Their preparation was largely algebraic, learned from within a structural analysis unit taught by, and for civil engineers, or from a study in Physics.

These students performed slightly worse than the students at UoM but the difference was not significant. Neither university had prepared their students for the apparently simple and similar tasks in the experimental protocol.

For most of the experimental tasks, students independently created identical incorrect solutions. Because the solutions were graphical concept diagrams, and not numerical or graphical scale diagrams, they were not inherently self-checkable. Students seemed unable to systematically confirm that their solution matched the known conditions of equilibrium. They could get the solutions partly correct, thereby satisfying some conditions (zero nett force was commonly implied) but appeared 'blind' to other conditions.

Since there were no forces or moments supplied in most tasks, and no points of application defined in most instances, students did not have a starting point for their strategy: unlike their earlier studies where some of this information had been supplied. Evidently, this 'new' type of problem, for which they had had little preparation (no preparation at MU) was difficult, and students adopted a simplified strategy where they focussed their effort on portions of the problem (partial equilibrium) and seemed comfortable in accepting, or overlooking other portions.

This behaviour is similar to the behaviour that we reported at ICED2001 (Field *et al*, 2001). In that study, student intuition was seen to be deficient, conflicting characteristics of a problem were resolved incorrectly apparently because of the students' inability to 'see' abstract forms. In both that study, and the present study, novice engineers have been unable to cope adequately with the perceived complexity of the task. In both cases, they were not able to develop a strategy for tackling these types of problem (the styles of problem were completely new to them), and without a strategy, the starting point, and subsequently, the finishing point, were somewhat arbitrary.

We acknowledge that experienced engineers do not suffer the same difficulties, but at yet it is not clear when, or how the necessary skills in structural distillation are developed. The work reported in this paper might serve as the beginning of a longitudinal study as the novices become more experienced over the following three years of their engineering courses.

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Investigating weaknesses in the underpinning mathematical confidence of first year engineering students

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Abstract: *The engineering community is becoming increasingly aware of the impact of the changes in mathematics education and culture throughout schooling over the past decade. Because the mathematical needs of engineering are specific* ***and*** *generic* ***and*** *immediate, and because of other pressures on engineering and engineering education, simplistic views and superficial "solutions" are tempting but at best hide the problem and at worst exacerbate it. The problems are complex, multi-faceted, and far-reaching. Tackling them requires understanding and identifying the essential issues, pragmatic but deep-thinking approaches, honest acknowledgement by all parties of the nature and diversity of the specific and generic mathematical needs of engineering, and real collaborative work. This paper tackles some of the understanding and identification aspects within a pragmatic framework that puts student welfare always at first priority. The initial and longer term effects of different first year student backgrounds are investigated within a framework of highly-supportive first year teaching and learning strategies. The paper also discusses the design and analysis of a diagnostic test with the dual aims of contributing to student self-help and to development of better engineering understanding and identification of weaknesses and strengths in current student backgrounds. Although the paper demonstrates the extent of the problems, it also demonstrates both the short and long term value of constructive and careful approaches.*

Keywords: *mathematical underpinning, first year engineering, specific and generic mathematical skills.*

Introduction

Since the late 1980's there have been fundamental and far-reaching changes in mathematics syllabi and curricula from grades P-12 in Australian schools. Each state has its own authorities responsible for syllabi, with a certain amount of national referencing and coordination taking place through the Ministerial Council on Education, Training, and Youth Affairs (MCETYA). The state authorities responsible for P-10 syllabi and grades 11-12 syllabi tend to be separate to some degree from Education Departments, and until recently have also tended to be separate to each other. They tend to be in charge of moderation and assessment of syllabi. Control and/or moderation of assessment tends to be mostly for grades

11, 12 with some combination of school-based and external assessment/moderation. Queensland seems to be the only state with complete school-based assessment moderated by a core skills test rather than some form of central examinations system.

The National Statement for Mathematics was published in 1990. It is not a national syllabus but has significantly influenced syllabi in grades P-10. Its form and emphasis embody much of the philosophy and culture of school mathematics education since 1990 and hence are a guide to the driving forces at school level over the past 10-15 years. Its emphases include

- maths enjoyment and achievement for everyone
- hands on approaches with emphasis on what is immediately practical and "useful"
- "real life" problem-solving and investigations involving experiments and collecting data and information
- technology

Its "syllabi" guidelines tend to be expressed in terms of a few main headings of the form "Experiences with ….. should be provided which enable children to….." with three to six possible activities under each main heading.

A characteristic of the past decade in school syllabi has been their expression in bullet point form, assuming that users possess sufficient knowledge and expertise to build sound, systematic and coherent development of student understanding and skills around those bullet points. Syllabi documents also tend to be written on the assumption that a range of base resources will be available for teachers and schools who will be comfortable in judging, choosing and using resources. Authorities tend to produce limited resources for grades 11-12, and in P-10 elaborations for teachers and some resources for classroom use.

A major component of the emphasis on "usefulness" has been the inclusion of statistics via Chance, Data (and Statistics) strands throughout the twelve years of schooling. This inclusion without sufficient resourcing, professional development and statistical input has produced its own set of effects and problems but statistics is not considered at all in this paper. In contrast to most disciplines, the mathematical requirements of engineering are of such extent and significance that they automatically cover the mathematical requirements of core statistics for engineers, and considerations of statistical education for engineers need to focus on the development and synthesis of statistical concepts, statistical thinking, tools and skills. Some strategies for this are discussed in MacGillivray (2002).

In school mathematics education the freedom of syllabi, the emphasis on holistic, life-related and inclusive approaches, and the move to criteria-based or outcomes-based assessment, have enabled the development of some outstanding mathematical teaching and learning strategies and resources by teachers with confidence, commitment and expertise for the relevant levels, with appropriate professional and authority support. However the past decade has also been one of increasing scarcity of mathematically-trained or mathematically-comfortable teachers and mathematically-aware educational authorities. Consequently there have been many downsides, particularly from grades P-10, that impinge on senior school, on an increasingly wide range of tertiary disciplines, and significantly on disciplines such as engineering that depend crucially on both specific and generic mathematical skills and confidence.

Similarly there have also been some outstanding teaching and learning developments in mathematics, statistics and engineering by individuals and groups in tertiary education, but the constantly increasing pressures from the changes in schooling; from the emphasis on flexible entry but non-flexible first year courses; and from the general tendency to trivialise the roles and needs of mathematical skills; have increased the challenges as rapidly as the innovations. For further discussion and references on some aspects, see MacGillivray and Moody (2001).

Before moving to the specific educational contexts in which the data have been collected and analysed, some general examples that are representative of Australia, and of other countries also, illustrate the types of challenges facing senior mathematics and tertiary teachers, particularly in disciplines such as engineering, science and technology. After outlining the specific educational contexts and teaching and learning strategies for the first year engineering groups that are the subject of this paper's investigations, the paper examines the effects and outcomes of student backgrounds, study and support during their first year, and analyses the results of a diagnostic test with reference to the overall first year data.

Some general mathematical challenges in the tertiary context

Many of the downsides of school mathematics over the past decade are associated with widespread lack of understanding of the pivotal and underpinning roles of specific and generic mathematical skills, the time necessary for their development, the need to provide nurturing across the full spectrum of mathematical capabilities, and the interdependence of mathematics and technology. A characteristic of weaknesses in mathematical skills and confidence is that such weaknesses often make their presence felt only when they are needed as stepping stones to further conceptual development or as small steps in larger or more complex real problems, and the "older" the weakness, the more difficult it is for students and teachers to strengthen it.

A prime example is the lack of attention to developing confidence in fractions, which seems to have its roots in misunderstandings of the role of technology, and which causes difficulties and frustrations for teachers and students at senior and tertiary levels across many disciplines, with complaints coming from areas ranging from accounting to nursing. Without comfort and confidence with addition, inversion, simplification and "cross-multiplication" of fractions, a student has a gnawing weakness that can constantly inhibit quantitative development.

Lack of understanding of the many roles of mathematical development plus emphasis on inclusivity and the immediately "useful", have delayed or inhibited algebraic development for many in the "top half" of primary and junior secondary cohorts, leaving them vulnerable to a range of weaknesses whenever algebraic thinking or skills are required for further development at senior secondary or tertiary level. Such skills and thinking are often taken for granted in disciplines that depend on representational thinking (such as in computer programming) or the representational modelling that is essential in quantitative business areas, sciences and engineering. What is called "mathematical modelling" at the school level with its emphasis on data collection and trial and error matching with a small number of simple already known models, has little in common with tertiary level mathematical modelling that depends crucially on confident representational thinking and skills.

The mathematical modelling of quantitative business, science, engineering and information technology also depends on confidence with functional thinking that in its turn depends on algebraic skills. An interesting example for engineering contexts of the combination of over-emphasis on spatial aspects and under-emphasis of algebraic and functional aspects, is the increasing student difficulties with sine and cosine as functions, resulting in such mistakes as treating sinx as sin*x or sin(cx) as sin(c)sin(x).

It is sufficiently difficult for tertiary teachers in mathematics departments to keep well-informed and to allow for the details of changes of school backgrounds unless they are directly involved in school syllabi. For tertiary teachers in engineering departments it is doubly difficult, not only because of lesser contact with the broad area of mathematics education but also because the specific and generic mathematical thinking and skills they personally use in their discipline have become so familiar to them that it is not possible to retain full awareness of how and when they acquired these skills.

The educational context of the subject cohort

At the Queensland University of Technology (QUT) the stated assumed mathematical background for engineering and science is a pass in Queensland's senior Mathematics B (or equivalent) which is outlined below. Considerably more than half the entering engineering students also have Queensland's senior extension mathematics subject, Mathematics C (or its equivalent), also outlined below. It is not permitted to sufficiently cater for the two different groups of engineering students by allowing those without the extension Maths C to do an extra subject as it is for Science and other students planning a major, co-major or minor in mathematics. Under the restrictions, the most that can be done is to provide different first semester subjects for the two groups, aiming to provide as much as possible similar bases for all the engineering subjects including the second first year engineering mathematics subject, with enriched consolidation and applications for those entering with the extension mathematics. For ease of reference in the remainder of the paper, the subject for those entering with passes in Maths B and Maths C (or equivalents) is coded MAB131, and the subject for those with a pass in Maths B only (or equivalent) is coded MAB180.

QUT's School of Mathematical Sciences collects data on every entering student to carefully screen and advise students to ensure that all students are appropriately enrolled. This task becomes more demanding each year, but is of the utmost importance for student welfare in both the short and long term. Note that experience has demonstrated that it is counter-productive for students with reasonable passes in Maths B and C to be in the same initial subject as those with Maths B only. Students without Maths B have almost no algebraic skills and have never seen the concept of a function. These students need to do a subject that attempts to "make up" for Maths B before they can cope with any engineering subjects, but it takes extraordinary strength and dedication on their part to make up for the lack of a core algebra- and function-based senior high school subject.

To provide maximum opportunity for the diversity of first year engineering students to engage, to gain mathematical confidence, and to combat false confidence, a system that enables students to combine flexible, formative and summative assessment in an individual but highly supportive way, was introduced in 1999 (Coutis, Farrell and Pettet, 2001). The exam assessment is divided into three sections, A, B and C, tests on which can be taken in weeks 5, 9 and 13. Tests on each are also provided at the end of the semester and students can choose for each paper to take their during-semester mark or to sit the end of semester paper(s) with their best result in each section used. In addition the weekly tutorials involve a 5-10 minute quiz and these tutorials can also be used to contribute to assessment. Most students take the opportunity to try the tests during the semester, and the weekly tutorials have almost full attendance. For example in 2003, 96% of MAB131 students chose to do paper A in week

5, and 89% of MAB180 students chose to sit their paper A in week 5 also. All students no matter what their background or capabilities, approve this highly structured, maximum opportunity, system.

Tables 1 and 2 provide a brief outline of Maths B and Maths C. As the semester 2, year 1 subject MAB132 includes Laplace transforms and introductory differential equations in engineering contexts, it can be seen how much the students need to gain in their first semester.

Topic	Comments	Proportion of subject
Introduction to functions	First time seeing notion of a function	1/6
Rates of change	Introduction to concept of instantaneous rate, rate of change and derivative; derivative of sums, differences, products	1/7
Periodic functions and applications	Sine, cos and tan – graphs and applications; Pythagorean identity; derivative of sin and cos	1/7
Exponential and logarithmic functions and applications	First time see log and exp; includes index laws; compound interest; derivatives of exp(x) and log(x)	1/6
Optimisation using derivatives	Max and min; stationary points; applications	1/8
Introduction to integration	Area under curve and definite integral; integral of x^n, exp(x), 1/x	1/8
Applied statistical analysis	Exploring data; distribution, expected value; use of binomial and normal; test of a proportion	1/8

Table 1: Outline of Queensland's senior Mathematics B syllabus

Topic	Comments	Proportion of subject
Introduction to groups	A little on concepts and uses	1/30
Real and complex numbers	Roots of quadratic with negative discriminant; cos(x) + i sin(x); complex plane	1/8
Matrices and applications	Emphasis on arrays; matrix multiplication	1/7
Vectors and applications	Scalar product; forces; winds	1/7
Calculus	Integration; solving simple differential relationships	1/7
Structures and patterns	GP's, AP's, sequences, series, permutations, combinations, induction	1/7
School option (six options provided including linear programming and introductory modelling with probability)	Dynamics is a popular choice. Another is Advanced periodic and exponential functions, e.g. sinh, cosh,..	1/7
School option (a school may submit one of its devising)		1/7

Table 2: Outline of Queensland's senior Mathematics C syllabus

The Maths Access Centre support and the outcomes

As in other universities in Australia and the UK, a mathematics support centre has also been established, in 2001, called the Maths Access Centre (MAC) (Coutis, Cuthbert and MacGillivray, 2002). The MAC provides at least some support to all students studying at least one mathematics subject, but provides particular support sessions and test preparation workshops for first year engineering students many of whom are grateful and enthusiastic supporters of the MAC, to the extent that there are now also provisions for second year engineering students. Cuthbert and MacGillivray (2003) give an overview discussion of the impact of the MAC support.

For the first year engineering students, who have the opportunity to attend student-driven support weekly support sessions and/or test preparation workshops, data have been collected and analysed, providing informative quantitative evidence that support staff and student qualitative experience. In the regression analyses below, regression diagnostics are not reported but all indicate model validity. It is also to be noted that attendance at test preparation workshops is highly correlated with support session attendance in all three subjects.

In their first semester, for those entering with Maths C, attendance at the test workshops has more effect than support session attendance (see below), but ***within*** those students who attend at least some segment of one of these, the amount of time spent at either workshops or tutorials is not significant. However for those students with just Maths B, not only are both workshop and support session attendance significant (see below), but within the group who attend at least some segment, the amount of time spent at support sessions is significantly beneficial. Below are the regression outputs analysing the effects in 2002 of the optional week 5 assessment (a1), the number of test workshop hours (wshop) and the number of support session hours (tuts) on the final % in the unit for those entering with Maths C (finalC – 224 students) and entering with Maths B only (finalB – 220 students).

The regression equation is
finalC = 17.8 + 0.797 a1 + 1.59 wshop + 0.588 tuts

Predictor	Coef	StDev	t	p
Constant	17.770	2.419	7.34	0.000
a1	0.79709	0.04749	16.8	0.000
wshop	1.5854	0.8740	1.81	0.071
tuts	0.5882	0.8493	0.69	0.489

s = 14.49 R-Sq = 58.6% R-Sq(adj) = 58.0%

The regression equation is
finalB = 26.4 + 2.06 a1 + 1.05 wshop + 1.12 tuts

Predictor	Coef	StDev	t	p
Constant	26.411	2.195	12.03	0.000
a1	2.0613	0.1099	18.76	0.000
wshop	1.0487	0.3512	2.99	0.003
tuts	1.1220	0.3474	3.23	0.001

s = 10.60 R-Sq = 63.2% R-Sq(adj) = 62.7%

In the second semester subject, MAB132, after allowing for the first semester result (sem1%), the optional week 5 assessment (a1) and workshop attendance (wshop) (all three being statistically significant and beneficial), the students' school background (sem1unit – an indicator variable) is still highly significant, on average giving a difference of 10% in the final mark (final2) after allowing for the other variables, as shown in the output below. The strength and size of the effect of their school background after successfully completing semester 1 has surprised staff who expected to see some effect but not of this magnitude.

The regression equation is
final2 = - 27.4 + 0.313 a1 + 1.07 wshop + 10.5 sem1unit + 0.946 sem1%

Predictor	Coef	StDev	t	p
Constant	-27.417	4.218	-6.50	0.000
a1	0.31350	0.05287	5.93	0.000
wshop	1.0664	0.3519	3.03	0.003
sem1unit	10.459	1.846	5.66	0.000
sem1%	0.94640	0.07297	13.0	0.000

s = 12.82 R-Sq = 70.9% R-Sq(adj) = 70.5%

The above analyses indicate that all students benefit from attendance and participation in classes designed to directly support student learning. Those without the extension school mathematics need to engage ***and*** they benefit significantly from time with extra face-to-face help. For those with the extension school maths subject, the advantages are not only clear but are also long-lasting. The year after the establishment of the MAC, there was a significant drop in failure rates in 2nd year mathematics subjects for engineers, indicating that the MAC not only helped students in their first year, but also helped students acquire sufficient confidence and learning skills to take with them into subsequent study.

The 2003 diagnostic test and results

During the past two years, diagnostic tests have been researched and pilots developed and trialled. It has been found that local details are of such importance that tests developed elsewhere are of little value. It has also been found that web-based diagnostic tests are of very limited usefulness for both students and staff. In 2003, a diagnostic test was administered in the second week of classes with 211 MAB180 students and 242 MAB131 students taking the test. The test was based entirely on Maths B core work with 19 multiple choice questions in 20 minutes. No prior warning was given so the only preparation was the revision of the first week. The students were very happy to do the test as it is designed to help them identify their individual strengths and weaknesses in core skills.

Great care is needed in designing such tests to balance a range of factors including: coverage of typical problems without combining too many in individual questions; and helping the students feel at least some confidence in themselves. For most questions, incorrect alternatives embodied typical mistakes, but for others the alternatives were completely "off the mark". The table below reports the questions and responses with comments. The original order of the questions is retained rather than grouping them by topic because of the significance of the non-responses over the test.

	Question in brief	Choices	% of cohorts all	180	131	**Comments on responses**
1	Factorise $4xy-12x^2y$	Correct $4xy(1-3x)$	84	83	85	Most students can do simple factorisation
		$4(xy-3xy)$	2	1	2	Saw 4 as a common factor but not x or y
		$4x(y-3y)$	3	3	2	Saw 4 and x but not y as a common factor
		$xy(4-12x)$	8	9	8	Not recognised that 4 was a factor of 12
		No response	2	3	2	Some did not know what factorisation was.
2	Solve $3x-5=x+15$	Correct 10	87	87	87	Most can solve a simple linear equation
		2.5	1	1	1	Could not change sign when rearranging.
		5	10	11	10	Could not rearrange the formula correctly
		4	0	0	0	
		No response	1	1	1	
3	$\sin^2(\frac{x}{2}) + \cos^2(\frac{x}{2}) =$	Correct 1	77	74	80	Most students are familiar with this
		1/2	7	8	7	Angle halved so answer should be also?
		x/2	5	5	5	
		None of above	5	7	3	
		No response	6	6	6	
4	Differentiate $y=3x^2+5$	Correct $9x^2$	96	96	96	Compare with question 8.
		$9x^2+5$	2	2	2	
		x^4+5x	1	1	1	
		$3x^2$	-	-	-	
		No response	2	1	3	
5	Factorise $9ax^2-36ay^2$	Correct $9a(x-2y)(x+2y)$	70	57	81	Most MAB 131 students could factorise completely but only over half of MAB 180
		$9a(x-4y)(x+4y)$	10	14	6	Knew it was the difference of two squares but did not see that $2^2 = 4$
		$9a((x-2y)^2$	14	19	9	thought that $x^2-4y^2=(x-2y)^2$
		$3a(3x-2y)^2$	3	6	1	Could do partial common factor then as above
		No response	4	4	3	
6	Solve $x+2=-\frac{1}{x}$	Correct -1	62	47	75	Less than half MAB 180 could solve this
		1 or -1	16	20	12	Thought required two answers.
		-1/3	6	10	4	
		-1/3 or 1/3	7	11	3	
		No response	9	11	6	A few did not know how to do this
7	$\int \frac{1}{x^3}dx$	Correct $-\frac{1}{2x^2}+c$	29	21	35	Typical of all first year students
		$\frac{1}{4x^4}+c$	11	9	14	Common mistake
		$\ln x^3+c$	41	51	31	An increasingly common mistake
		$\frac{-3}{x^2}+c$	13	11	15	Common confusion of differentiation and integration.
		No response	6	8	5	

8	Derivative of $3x+b$ wrt *x*	Correct 3	40	73	11	
		$3+b$	8	14	2	did not see that d/d*x* of constant is zero
		4	7	7	7	d/d*x* (3*x* and *b*) = 3 + 1 = 4
		b	36	1	65	Very puzzling responses from MAB131
		No response	9	4	17	
9	$\frac{d}{dx}\sin(2x)\cos(x)$	Correct $2\cos(2x)\cos(x) - \sin(2x)\sin(x)$	33	59	11	**Note** the high correct response for MAB 180 compared to MAB 131 - MAB 180 had just reviewed the product rule
		$\sin(2)(\cos^2 x - \sin^2 x)$	4	4	4	
		$2\cos^2 x - \sin(2)\sin^2 x$	21	5	35	Part product rule but made mistake while using the chain rule
		$2(\cos^2 x - \sin^2 x)$	31	13	47	Note the effect of no revision on MAB131
		No response	10	18	3	
10	The graph of $y=(x+1)^2$ is (choices provided)	Correct	64	36	88	MAB 131 more confident than MAB 180
		like $y=x^2$	6	3	8	
		like $y=x^2+1$	22	46	2	MAB 180 thought it was shifted up
		like $y=x^2-1$	2	4	1	
		No response	6	11	1	
11	$\int e^{-2x}dx$	Correct $-\frac{1}{2}e^{-2x}+c$	51	47	55	
		$-2e^{-2x}+c$	26	17	34	Typical mistake
		$\frac{1}{2}e^{-2x}+c$	6	10	2	Nearly correct but forgot the negative sign at the front
		$2e^{-2x}+c$	2	2	1	
		No response	15	23	7	High percentage MAB180 not responding
12	Derivative of ax^2+b with respect to *a*	Correct x^2	35	12	55	MAB 180 demonstrate typical result of lack of maths familiarity
		$2ax$	41	53	31	
		$2ax+b$	8	10	6	As above but also did not see *b* as a constant
		x^2+1	3	2	3	
		No response	13	22	5	Again high % MAB180
13	Evaluate $f(x)=\frac{3x+2}{3x-2}$ $when\ x=\frac{1}{2}$	Correct **-7**	66	42	87	MAB 131 general numerate confidence
		-3	4	6	2	
		-7/4	8	12	5	Typical of fraction problems (-7/2)/(1/2)
		2/7	2	3	2	
		No response	19	37	4	MAB 180 students slow
14	$\frac{d}{da}(x^a)$	Correct $x^a \ln x$	12	6	17	
		ax^{a-1}	45	47	43	Correct if diff wrt to *x*
		$a\ln x$	14	6	22	MAB 131 recognise d/da but not good with exponent
		x^a	5	4	6	
		No response	24	37	12	High % MAB180

15	$\frac{d}{ds}(s \ln s)$	Correct $\ln s + 1$	24	17	31	Very low correct response
		1	19	16	21	Did not use product rule
		$\ln s + s$	6	6	6	Some use of product rule
		$\frac{1}{s}$	23	18	27	Know that d/dx of ln x = 1/x
		No response	28	44	15	Note rapidly increasing % MAB180
16	$g(x) = \frac{2x^2+1}{x-1}$ find g(-2)	Correct -3	51	24	74	MAB 131 students doing well
		-5/3	7	5	8	
		9	4	4	3	
		5/3	4	3	5	
		No response	35	63	10	Very high % MAB180 – very slow
17	Factorise $x^m - x^{2m}$	Correct $x^m(1 - x^m)$	34	18	49	
		$x^m(1-x^2)$	15	10	20	Indice rules $x^{2m} = x^m \times x^2$
		$x(x^{m-1} - x^{2m-2})$	4	4	5	Indice rules $x \times x^{2m-2} = x^{2m}$
		None of above	8	5	11	Thought all choices wrong
		No response	38	64	14	near end of paper
18	Simplify $\frac{a^2-1}{a+1}$	Correct a - 1	39	18	57	
		$\frac{1}{a+1}(a^2-1)$	11	5	16	Did not see diff of two squares - so altered the format which is true but not simplified
		$(a+1)(a^2-2a+1)$	6	5	7	
		a+1	2	1	2	
		No response	42	70	18	near end of paper
19	Complete the Square x^2+3x-7	correct $(x+\frac{3}{2})^2 - \frac{37}{4}$	25	8	40	
		$(x+3)^2 - 7$	7	5	9	guess or didn't divide 3 by 2
		$(x+\frac{3}{2})^2$	12	10	13	left off constant
		$(x+\frac{3}{2})^2 - \frac{9}{4}$	5	5	6	Did not subtract the 7
		No response	50	71	31	

Table 3: Diagnostic test 2003, results and comments

Conclusion

It must be emphasized that the diagnostic test is on core skills of the senior maths subject (or its equivalent) that all the students had passed. As well as helping students (and staff) identify individual and general technique strengths and weaknesses, the diagnostic test also illustrates the over-riding challenge for students and staff at senior secondary and tertiary levels, and why support programs such as the MAC make such a difference, and why students with the extension senior maths subject have such an advantage – provided they also engage in their learning. Those entering with the extra extension subject are better, more confident and comfortable with the core techniques of Maths B simply because they have greater contact with generic mathematical skills. The challenge for all is that the students who need mathematical skills and confidence post-school have not gained sufficient mathematical comfort and confidence in grades 1-10. As an experienced teacher from both school and tertiary levels commented:

‘The problems occur when a "basic" is a tiny part of a larger problem ... Because the "basic" is not second nature they rush it or confuse it and hence get it wrong. For example, engineering students" ...with problems... "will often know how to proceed in a given complex problem but mess up a "basic" and as a result get to a point where they can proceed no further. Even if we could find the time to devote to "basics" there is the question of the morale of the students who are weak in "basics". I have a feeling that this is a reason that many who need help do not seek it. They feel foolish because they cannot do things that they see as "simple".’ Carter (2002)

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Curriculum Diversity in a Common First Year

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Abstract: *This paper reports on the curriculum structure, underlying rationale and successes of the flexible 'common' first year of the Bachelor of Engineering at the University of Queensland. Pressures to accommodate both increasing depth and breadth of study, while at the same time increasing flexibility and choice to suit an increasingly diverse student cohort being educated for increasingly diverse employment opportunities and careers are discussed.*

Keywords: *Common first year, diversity, early specialisation, curriculum, flexibility*

Introduction

Historically, the BE program at the University of Queensland (UQ) has had a common first year. We have for many years admitted approximately 500 engineering students, predominantly high school leavers drawn from schools throughout Queensland and Northern New South Wales, under a single quota into the common first year of study. This is intended to provide a broad yet strongly relevant base leading into further study in all divisions of engineering offered at the University. There is currently a choice of 12 distinct disciplines (and one sub-discipline) of engineering at UQ. Despite this large range of offerings the common first year was considered to be advantageous for the following reasons.

Students leaving high school in Queensland are relatively young at an average age of $17^1/_2$. They are required to complete only 12 compulsory years of schooling whereas their counterparts in southern states do 13 years. They often have ill conceived and poorly defined notions of engineering, and are unsure of whether engineering is the right career choice. Many are equally confused about the distinguishing characteristics of the different engineering disciplines available for study and the associated employment and career opportunities. The common first year gives these students an opportunity to develop their understanding of engineering, appreciate its breadth, and explore the nature of its constituent disciplines before making a choice of one particular discipline. Anecdotal evidence over many years indicates that students considered this to be a positive influence on their choice of engineering at UQ.

From a University perspective the admission of engineering students under a single quota to a common first year also has advantages. Engineering is promoted and marketed to the schools' community as the career option, rather than a fragmented approach by individual engineering disciplines, each competing for a share of the intake and EFTSU. It is advantageous, we believe, to try to describe and market a unique and distinguishing set of characteristics that identifies and differentiates engineers, irrespective of the discipline to which they belong. Examples of how these characteristics translate into the various disciplines is always of interest to the prospective student, but is there to support the message about the overarching identity of the engineering profession as a collective and in its entirety.

However, the very breadth of engineering is an issue when designing a common first year to suit all constituents. The diverging nature of engineering is in part due to emergent disciplines such as computer systems engineering, and biomedical engineering which do not rely solely on the traditional fundamentals of physics, maths and chemistry around which the common first year was routinely built. The dynamic growth in the cognate sciences underpinning these emergent fields e.g. information technology, biology must somehow be incorporated into an already overcrowded curriculum. For example, chemical engineering undergraduate programs were formerly based on the sciences of chemistry, mathematics and physics. The growing field of bioengineering at the interface between chemical engineering and biology, means many chemical engineering programs now include a compulsory unit of biology. Figure 1 shows the range of engineering disciplines available in undergraduate programs at UQ and their cognate sciences. Mathematics is not identified on the diagram as it is considered to be equally important and universal across all engineering fields.

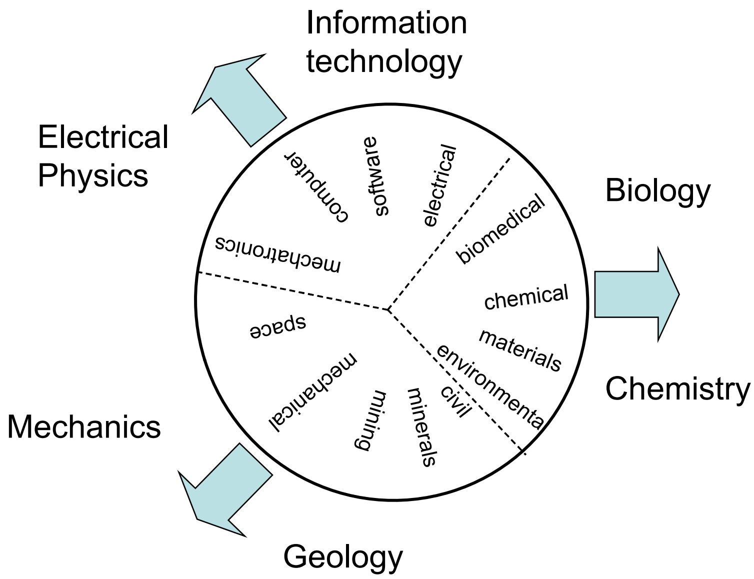

Figure 1: Growth in Engineering Disciplines & Cognate Sciences

Furthermore, there is a blurring of the boundaries between science and engineering, arising in part because engineers now work across multiple scales varying by many orders of magnitude with exciting developments occurring at the extremes of scale. Examples are nanotechnology and chemical product design, primarily concerned with what happens at a molecular scale, whereas environmental modelling operates on a regional, national, even a global scale. There is also increasing differentiation within the profession with regard to engineering roles such as design, systems engineering, and the pervasive use of information technology in engineering. The current debate within the professional and public press (Boshier, 2003) revolving around Rosalind Williams' *Retooling: A Historian Confronts Technological Change* (2002) is evidence of the continuing expansion of engineering and its 'identity crisis'.

There is also increasing diversity within the student body. Students enter from increasingly different backgrounds. Even though our first year intake is still predominantly school leavers, they have a wider range of abilities, educational experiences and interests than ever before. For instance, several years ago the entry requirement for compulsory advanced mathematics was abolished, and now approximately one third of our cohort enters with only one high school mathematics subject, Maths B. Similarly they bring a huge range of study interests, ambitions and career aspirations. It is no longer sufficient to offer inflexible degree programs with little or no choice, and that lead only to the development of depth in one chosen area of engineering e.g. civil engineering.

Students are now aware that engineers are increasingly engaged in complex and multidisciplinary work. There is a need for those with both highly specialised knowledge and narrowly focused skills sets, and for those with a broader skills set. Engineering students want to combine engineering not only with science, but also with business management, law, foreign languages, psychology and many others. The proliferation of and demand for dual degrees at Universities across Australia is testimony to the growing student recognition of the value of a broader education and multiple qualifications, as preparation for the complexity and multi-disciplinary demands of the modern work place. Thus there is now a balance to be reached between the demands for depth and breadth in the education of engineers in undergraduate programs.

In response to the growing demands arising from the increasing diversity within the profession and students, the common first year at UQ was recently reviewed with the critical issue seen as the depth versus breadth dilemma. What is an appropriate balance between depth and breadth within a core engineering curriculum? And how can we accommodate flexibility to give students choices with respect to adding further depth or breadth to their studies?

It is a tall order to design a first year program that caters for the interests of 500 students in disciplines that range broadly from biomedical to software engineering. Of the students entering first year from high school, about half of these know, or think they know, which engineering specialisation they wish to pursue, and want to feel that they are getting on with it. This is particularly true in the areas of Computer Systems, Electrical, and Software Engineering. The other half are undecided and value a year of broad exposure to available specialisations before deciding on one in Year 2. Approximately ten percent of the cohort also identify at the start of their studies their intention to take out a second degree, the most popular being business management, commerce and arts. Year 1 is now designed to cater for all groups by providing for 'direct entry' into a specialisation, or enrolment in one of two general plans that keep a number of options open. Dual degrees are available in most, but not all direct entry, and both general plans.

The General Plans

Experience indicates that the undecided students fall mainly into two groups, those deliberating among Computer Systems, Electrical, and Software Engineering, and those deliberating among the other specialisations. Therefore two general plans are designed with these two groups in mind. Students who wish to defer some choice of specialisation to their second year are advised to enter one of the two general plans shown below in Table 1

General Engineering Plan A Leads to Year 2 specialisation in	**General Engineering Plan B** Leads to Year 2 specialisation in
Chemical	Computer Systems
Civil	Electrical
Environmental	Software
Materials	
Mechanical	
Minerals Process	
Mining	
Early Specialisation in mandatory for	
Mechatronic Engineering	
Mechanical & Space Engineering	
Early specialisation is optional for all general plan disciplines	

Table 1: First year BE enrolment options

Details of the structure of the general plans is shown below

Compulsory Plans A & B	**General Plan A Compulsory**	**General Plan B Compulsory**	**Electives**
Introduction to Professional Engineering Mathematical Foundations* Calculus & Linear Algebra I Multivariate Calculus & Ordinary Differential Equations * compulsory for students without Senior Maths C	Applied Mechanics Physics & Engineering of Materials Applied Chemistry for Engineers Engineering Thermodynamics	Introduction to Computer Systems Introduction to Software Engineering Introduction to Electrical Engineering	Genetics & Evolution Molecular & Microbial Biology Human Biology Ecology & Environment Sustainable Development of Resources Earth Processes & Geological Materials for Engineers Electromagnetism, Optics, Relativity & Quantum Physics I Physical Basis of Biological Systems Physical Principles of High Technology

Table 2: Curriculum Structure of the Common First Year

All students irrespective of which general Plan or 'direct entry' specialisation they choose, must complete the compulsory courses shown in the first column in Table 2. Depending on their entry level mathematics, this includes 2 or 3 mathematics courses. The other compulsory course for all first year engineering students is Introduction to Professional Engineering. This course targets development of the broader engineering graduate attributes and also introduces students to the breadth of engineering practice and issues. To realise the learning objectives, the course consists of team project work and a series of keynote lectures addressing a broad range of engineering issues. However most of the student activity and assessment is built around the substantial team project. Trendy topics are chosen and framed to simulate a real life engineering project and we try to match students with their preferred projects. However the processes associated with development of broad graduate attributes and skills, such as team work, communication and project management, are the main learning objective and are common across all 5 projects. Project plans, project management logs, written team reports and oral presentations are all incorporated into the team project component of the course and are assessed. The projects run across the entire semester and are therefore a substantial component of the students' first semester workload.

The number of electives that can be chosen depends on the entry level mathematics and which general plan is chosen. Some students have no electives, eg those without advanced high school maths and entering General Plan A. Students with advanced high school maths have at least one elective in first year irrespective of which general plan they enter.

Students who are confident with a choice of specialisation may elect to follow a 'direct entry' or 'early specialisation' plan that opens up a greater choice of electives within first year. For example, an 'early specialisation' plan for chemical engineering nominates only chemistry and thermodynamics from the General Plan A list as compulsory. 'Early Specialisation' chemical engineering students interested in biomedical engineering or biotechnology can choose biology electives in place of the other two compulsory Plan A courses, Applied Mechanics and Materials. 'Early specialisation' civil engineering students need only Applied Mechanics and Materials. Electives for civil engineers can be Geology, and Sustainable Development of Resources. Of course, any of the compulsory courses from either of the General Plans are also legitimate 'early specialsiation' electives.

Dual degrees students wishing to follow a General Plan can also be accommodated. Dual degree students undertaking Arts or Business as their second degree would normally defer two of the first year engineering courses to start the second degree. These students require careful academic advising on deferring engineering courses according to likely or unlikely choices of discipline.

Discussion

The General Plans and 'Direct Entry' arrangement are successful in managing the conflicting students demands for 'getting on with what they want to do within a chosen specialisation' and deferring choice of specialisation. Enrolment data indicates that approximately half of our first year students nominate an early specialisation, confirming our earlier conviction that about half of the intake have made a choice of engineering discipline before they arrive at University. Complaints from this subset of the first year cohort about the frustrations of being in a broad based first year have now disappeared. Of the remaining half that follow one of the general plans, most wait until their second year of study to nominate their chosen specialisation, thereby taking full advantage of the extra year.

The growth of the engineering and science interfaces and the broadening of the science electives available in first year engineering, particularly the inclusion of biology, open up new pathways into engineering from the sciences. There has been growing interest in engineering from students with a biology/biotechnology background. This includes students who have not or would not have entered engineering through the usual matriculation from school. The development of new dual degrees such as the Bachelor of Engineering/Master of Biomedical Engineering, and Bachelor of Chemical Engineering/ Bachelor of Biotechnology has attracted strong interest from such students. And there is greater representation of engineering courses in associated science degrees. This contributes to the continuing diversification of our student body and ultimately the engineering profession at large. This diversification is a desirable long term outcome for the profession and was identified as a significant issue for engineering educators in the most recent Australian review of Engineering Education (IEAust, 1996)

The course, Introduction to Professional Engineering, continues to be a very successful part of the restructured 'common' first year. The use of a project-based course as a vehicle to begin developing generic graduate attributes in an engineering context has proved effective. Students like being given a choice of project, they enjoy the project work, and the team work is a useful way of establishing collaborative study groups within a large cohort just beginning their University studies. In the recent IEAust accreditation visit to the University of Queensland, this course received plaudits from both the student body and the accreditation review panel who commended it as an exemplar for further development of project centred learning in later years and across all engineering disciplines (IEAust, 2002).

We believe our restructured 'common' year, with the practice course, Introduction to Professional Engineering, and its general plans, or a 'direct entry' option represents an excellent balance between the demands for early and deferred specialisation. It combines flexibility of choice and recognition of the expanding scientific base of engineering practice with a common core of study, including a broad based introduction to professional engineering that exposes students to the breadth of engineering. The curriculum is structured to accommodate both the student who is interested in depth within engineering study, and the student interested in broadening studies outside a conventional engineering program.

We believe this is an excellent model for encouraging and facilitating diversity while retaining most of the advantages of a common first year of engineering studies. It appears to have worked well for all stakeholders since its introduction at the University of Queensland three years ago. And as a final accolade, there have been recent expressions of interest in this approach to first year from engineering schools of other Group of 8 Universities in Australia, thus validating our confidence in the strengths and attractiveness of our current flexible 'common' first year.

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Visiting the hall of mirrors: engineering academics' conceptions of sustainability

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Abstract: *Sustainability means different things to different people. In this paper we consider how engineering educators' conceptions of sustainability may shape the way they teach sustainability to undergraduate engineers.*
We begin with a snapshot of our research to-date. Our research has focused on what engineering educators might mean by 'sustainability', and has demonstrated substantial variation in the ways that engineering academics conceive of the concept. In light of this variation, we explain how and why we think sustainability should be simultaneously contested and agreed, and float the idea that this variation could be viewed as a useful 'toolkit of sustainability conceptions'. We also discuss some ways that embracing variation might assist academic capacity building and further develop undergraduate teaching of sustainability.

Keywords: *academic conceptions, professional development, sustainability*

Introduction

In 1996, David Thom professed a paradigm shift was upon the engineering profession, and that this shift would radically reorient professional engineering practice towards sustainability. Seven years hence, Thom's paradigm shift is in full swing and has wrought substantial changes in the operating environment of the professional engineer. We in engineering academia have joined this paradigm shift due, in part, to the Institution of Engineers, Australia's explicit requirement for a sustainability literacy component in those engineering courses it accredits (IEAust, 1999). This shift in focus away from development engineering and toward sustainable development engineering (Thom, 1996) has impacted considerably on those engineering faculties which have chosen to respond comprehensively (eg. University of Technology, Sydney (Parr *et al.,* 1997; Bryce *et al*., 2002); University of Newcastle [Evans *et al.* 2001]; Massachusetts Institute of Technology [Marks, 2002]).

A commitment to sustainability teaching and learning offers undeniable challenges to the academics charged with its implementation. Our collective experience at previous Australasian Association for Engineering Education (AaeE) conferences (1993 - 2002) suggests many Australian engineering academics are facing this challenge as autonomous and/or isolated educators with primary responsibility for the construction, delivery, assessment, and evaluation of sustainability teaching and learning within disciplinary schools. It is this pivotal and influential role as singular sustainability guides which underpins our current research focus, and the train of thought we now present. In this paper we aim to highlight the existence and nature of variation in engineering academics' conceptions of sustainability, and to ruminate on some of the opportunities and challenges this variation represents for teaching sustainability principles, ethics and practice.

The thesis underpinning our paper is that individual academic's conceptions of sustainability are fundamental and foundational in the construction, delivery and outcome of sustainability teaching and learning. And further, that embracing and working with the apparent array of different conceptions in the academe could enrich both the teaching <u>and</u> practice of sustainable engineering. Our thesis is informed by our research into engineering educators' conceptions of sustainability and four key ideas:

- ✓ our own vision of sustainability as a pluralistic concept;
- ✓ the notion of a range of conceptions as a 'sustainability toolkit';
- ✓ the potential for personal conception of sustainability to impact on approach to teaching sustainability;
- ✓ and the utility of conceptual diversity as a basis for capacity building within the engineering academe.

In the following section, we summarise our research findings to-date to provide the reader with a snapshot of the variation we have found in engineering academics' sustainability conceptions. We follow this snapshot with an exploration of each of the four ideas which underpin our thesis.

Variation in sustainability conception

It is often observed that sustainability is a contested concept (eg. Filho, 2000; Crofton, 1995). This conceptual contest is manifest in the application of sustainability to engineering problems, and is evident in the very different ways that various engineering educators approach the task of including sustainability content in coursework (eg. Boyle's pollution prevention approach [Boyle, 1999] compared with Clift's social engagement emphasis [Clift, 1999]). A good part of our research and thinking over the past three years has probed this idea of variation in conceptions of sustainability.

In our earliest work on variation in conceptions of sustainability, we conducted one-on-one interviews with a group of eight engineering academics and asked each participant the question 'What do you mean by sustainability?'. In this study, we examined the metaphors used by participants to explain or discuss what they meant by sustainability. These metaphors were viewed as representations of the participants' mental models of the concept. Each participants' view of sustainability rested on an objective of continuity and, although the focus of continuity varied between participants, we construe this to be an overarching theme. We perceived four metaphors during the study, they are described briefly in Box 1 below (see Carew and Mitchell (in prep - a) for further details).

Box 1: Four Metaphors for Sustainability

Sustainability as weaving – seeking to understand and draw together disparate technical and non-technical elements to create a cohesive but flexible whole.
Sustainability as guarding - guarding and apportioning exploitable resources and waste sinks to ensure they are not depleted too rapidly and/or are distributed equitably.
Sustainability as trading - quantifying the environmental and/or social and/or economic costs and benefits of a decision and trading them off against each other.

Sustainability as observing limits - recognising the existence, interconnectedness and limits of systems, and following a hierarchy in observing/applying system limits.

In the same interview study, we refined the focus to more specific (if somewhat arbitrary) aspects of sustainability by asking the participating engineering academics 'What do you mean by environmental sustainability?', 'What do you mean by social sustainability?' and 'What do you mean by economic sustainability?'. For this part of the study we used a phenomenographic orientation to differentiate between different views of these aspects of sustainability, and to generate representative conceptions (see Carew and Mitchell (in prep – b) for further details). The conceptions are listed in Box 2 below.

Environmental sustainability

- Recognition that exploitable resources provided by the environment are limited
- The need to conserve exploitable resources as long as possible

Social sustainability

- Respect for and consideration of community values in decision-making
- Enfranchisement of individuals and groups in the community
- Protection of human health and amenity
- Intergenerational equity in terms of access to resources or resource availability
- Ensuring, maintaining or developing human quality of life

Economic sustainability

- Long-term financial viability for discrete entities
- Using an economic framework which allows valuation of externalities
- Using economics as a tool to promote individual quality of life

Box 2: Some Conceptions of Environmental, Social and Economic Sustainability

At last years' AaeE conference we conducted a professional development workshop aimed at getting participants to articulate and share their own conceptions of environmentally, socially and economically sustainable engineering, and to consider similarities and differences between participants' conceptions. Twenty three engineering educators participated, each coming up with three or four ideas about what these three aspects of sustainable engineering meant to them. We then led a loose coalition of participants in attempting to group analogous conceptions and name the resulting groups. There were twelve groups named and each encapsulated a few dominant themes. Our attempt to group and demarcate conceptions was intended to generate further reflection and discussion amongst the participants. As would be anticipated with a systemic, values-laden concept like sustainability, it was difficult to establish consensus on how, where and why to differentiate between themes. We list the groups and themes in Box 3, below.

Box 3: 'Conceptions of Sustainability: Mapping The Territory' Outcomes from AaeE 2002 PD Workshop

- **Holism and society** – Respecting and preserving community, cultural diversity, quality of life. Taking into account the societal setting and social implications of technological action. Being human centred.
- **Appropriate design** – Technology appropriate to the context. Serving social need, keep pace with social change. Affordable inventions. Using local resources and skills. Improves standards of living.
- **Changing the development paradigm** – Thinking about the future, globally. Systems focus. Alternative economic frameworks, redistribution of wealth. Recognising limits to consumption.
- **Responsibility and balance** – Taking responsibility for engineering impacts on environment and society, on a range of scales (eg. local, global, temporal). Meets or balances human needs and wants.
- **Resource management/care** – Preferential use of renewable rather than non-renewable resources. Conservation of non-renewables. Recycling resources. Not using up the environment.
- **Safeguarding ecosystems** – Avoid/regenerate damage, foster thriving ecosystems. Sensitivity to all physical elements (eg. air, water). Maintaining biodiversity. Consider non-human entities.
- **Participatory processes** – Ability to listen and appreciate a variety of viewpoints. Involve many disciplines, decision-makers, stakeholders in decision processes. Consult with the community.
- **Business imperative** – Coming up with affordable and/or profitable solutions. Wealth creation and wealth distribution. Economic payoff over the long term.
- **Minimising impact** – Minimising or mitigating environmental impacts. Considering whole of lifecycle impacts. Protecting society and social diversity.
- **Philosophy** – Spiritual needs. Cradle-to-grave thinking. Considering the process and the task. Involving values. Engineering as serving or leading.
- **Integration** – The integration of social, environmental and economic systems.
- **Entropy** – We can only minimise impacts. The second law of thermodynamics makes sustainability impossible.

As the three studies discussed above indicate, there is a great deal of variation in the ways that sustainability is conceived of by the engineering educators we have surveyed. The value of documenting and discussing the existence and character of this variation lies in the opportunities and challenges it represents for infusing engineering teaching and learning (and hence the profession) with sustainability principles, ethics and practice. Before we explore this utility, it is timely to lay out something of our own conception of sustainability and how we reconcile our own perspective with the range of conceptions generated during our research.

Sustainability as a pluralistic concept

This section is based on the authors' combined ten or so years' experience in sustainability teaching, researching and consulting. In it we detail our conception of sustainability and explore how and why sustainability may be, and in our view should be, simultaneously contested and agreed.

Our observations of sustainability in action lead us to think that it may best be understood as a pluralistic concept. From this perspective sustainability needs to be a chameleon; an organic and flexible concept, able to be adapted to the myriad and plastic contextual influences which make each setting, decision or problem unique. As a pluralistic concept, we believe sustainability manifests as a set of basic principles like: exercising fairness, taking responsibility, being aware, systems thinking, recognising uncertainty and complexity, mitigating impacts, and being cogniscent of limits and elasticity (expanded discussion in Carew and Mitchell, 2001). In our conception of sustainability, these principles and their application need to be continuously viewed and reviewed from a critical or reflective position (Schön, 1983). It is at the stage of implementation, that pluralistic sustainability becomes a little slippery.

We see implementing sustainability as a process of decision-making whilst managing multiple relationships which involves participative and deliberative processes with representative stakeholders to generate shared understandings of the nature of 'the problem', and to explore, flex and personalise the above principles, before applying them to the broadest possible range of solutions, thereby determining a preferred course of action. This means that sustainable solutions or outcomes are a *product of the process* as opposed to a prescribed, generic set of technologies, procedures or outcomes. And the quality of outcome is judged, at least in part, by the *quality of the process* rather than the outcome, *per se*. A logical extension of this argument is that a commitment to a singular 'one right way' of actioning sustainability or a suite of 'sustainable technologies' is contrary to this notion of process and pluralism, and risks losing the flexibility and intimate contextuality we believe is required to affect sustainable outcomes.

This brings us to a question: How does our view of sustainability as a pluralistic process reconcile with the array of different conceptions we described in the previous section?

A toolkit of sustainability conceptions

A point of convergence between the array of sustainability conceptions we presented above, and sustainability as a pluralistic process is that the array of conceptions could represent a set of 'worked examples' of how our basic sustainability principles (fairness, responsibility, awareness, systems thinking, uncertainty and complexity, impacts, and limits and elasticity) might manifest. Furthermore, the differences or contradictions between some conceptions might be indicative of (and could help bring to light) contrasting underlying values held by engineering educators.

Viewed in this light, the array has great potential as what we call a 'toolkit of sustainability conceptions'. In other words, the array of sustainability conceptions could become a malleable, personalisable toolkit of thoughts and ideas about different ways in which the sustainability principles might manifest and/or be applied, which a person facilitating sustainable decision-making processes could use to enrich, catalyse, and/or inform the process.

A key potential hurdle here is that the application of pluralistic sustainability and the use of such a toolkit, is contingent on individuals accepting that one's own conception of sustainability is not necessarily 'the right one' for everyone else or for every situation. For individuals used to operating in a strongly positivist paradigm, this could be fundamentally challenging. This relates to Taylor's (2002) assertions about the need for engineering to recognise its 'illusion of control'. In a pluralistic approach, rather than any conception being 'right' or 'wrong', each would ideally be considered by a representative group of stakeholders, within the bounds of a specific problem, in a particular context and through the lens of an array of values-based priorities.

One of the keys to successful application of a pluralistic sustainability process is the recognition of, and (re)distribution of decision-making power. As Taylor (1996, 2002) points out, a substantial amount of the say in technology-related decision-making is routinely given over to engineers on the assumption that they have a rightful contribution to make on the basis of their technical expertise. This seems inherently reasonable. However, what is not so often recognised is the important role in decision-making of stakeholders as experts in their own needs, values and preferences. This (re)distribution of power is a challenging concept with the potential to send this paper off on a spectacular conceptual tangent! Instead, let us make a graceful segue into more manageable territory.

In the preceding few pages we have listed a spectrum of different ways that engineering academics might conceive of sustainability, we discussed our view of sustainability as a pluralistic process, and then described how an array of conceptions might be used to develop a toolkit of sustainability conceptions for use in pluralistic sustainability decision-making. We now train our focus back into the realm of engineering education, and consider some of the more direct implications that variation in sustainability conceptions might have for the professional development of engineering educators, and for sustainability teaching and learning at undergraduate level.

Utilising variation in engineering education

Conceptions as bases for professional action

For the past three years or so we have been investigating how engineering academics and students conceive of the concept 'sustainability'. Much of our research to-date has been founded on and informed by a model which draws an explicit link between the way that tertiary teachers conceive of a given concept, and their subsequent approach to teaching that concept. The model also draws a relationship between an academic's approach to teaching and their students' learning outcomes. We will now take some time to describe and explain this model, before exploring some of the implications for teaching sustainable engineering. Figure 1 shows our adaptation of what we call the Construct Model.

In Figure 1, the academic and student are shown inside an institutional frame which represents the regulatory, administrative, logistical and cultural constraints of the teaching/learning institution. The academic and student are represented as individuals who select their approaches to teaching/learning on the basis of their conception of the situation in which they find themselves. In this model, the term 'conception' is shorthand for a range of influences including: 'past experiences', 'expectations', 'impression' and 'understanding'. The Construct Model draws an explicit relationship between the academic's previous experiences and current understanding of teaching and of subject matter, their intentions regarding what and how they expect students to learn, and the subsequent approach they take to teaching and assessing that subject matter. The way that students choose to respond to the approach selected by the academic influences the success of student learning (student's learning outcome).

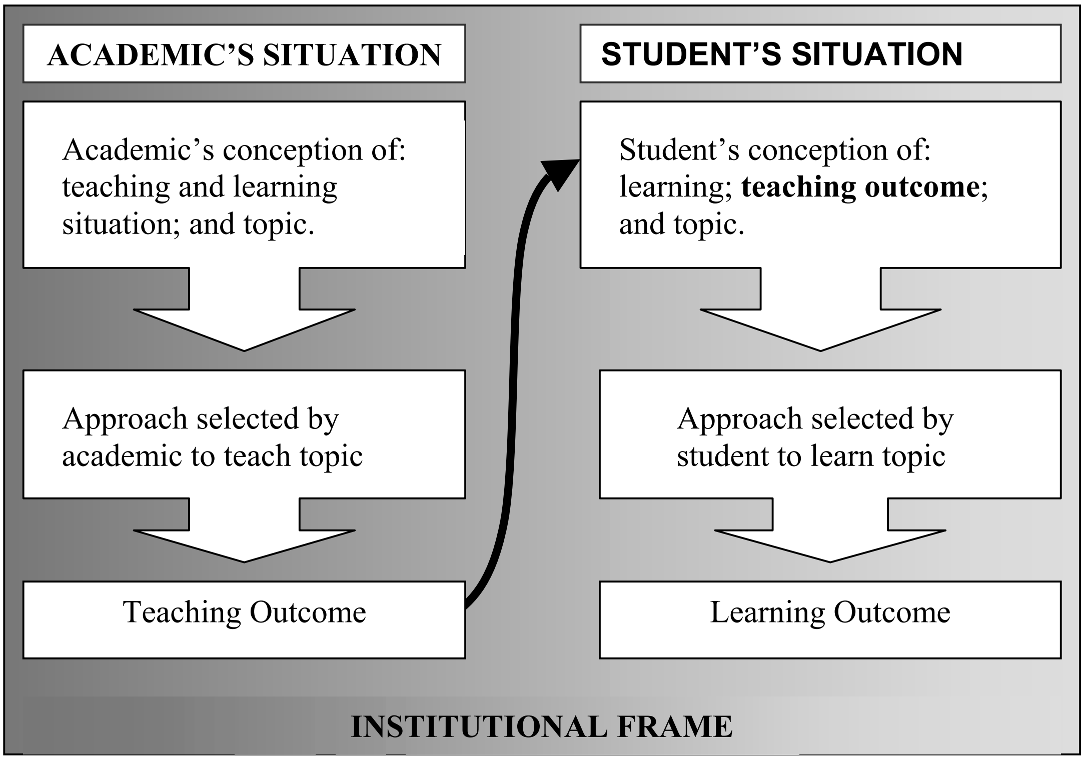

Figure 1: The Construct Model of Teaching and Learning (adapted from Prosser and Trigwell, 1999).

Thus far, models like the Construct Model have mostly been used by educational researchers interested in the causes of more/less successful student learning outcomes at tertiary level, and the focus has predominantly been on the part of the model which deals with how students behave in a teaching and learning situation (reviewed in Prosser and Trigwell, 1999). We, however, have found the Construct Model to be a useful tool for cogitating on the challenge engineering academics face in teaching sustainable engineering. In essence, the Construct Model infers a potential theoretical link between engineering academics' conceptions of sustainability, their subsequent teaching about sustainability, and their students' sustainability learning outcomes. This theoretical link reinforces our interest in exploring the way that engineering academics conceive of sustainability.

Earlier we observed that 'many Australian engineering academics are facing the challenge of infusing engineering curricula with sustainability as autonomous and/or isolated educators'. When we consider this statement in combination with the range of sustainability conceptions we presented in the first half of this paper, and the Construct Model's theoretical link between academics' conceptions of sustainability and teaching outcomes, it becomes apparent that engineering academics may be teaching fairly distinctive versions of sustainability to their undergraduate charges. Thus, if the teaching of sustainability is taken on by one or two motivated individuals within disciplinary engineering departments, students' may experience a limited range of sustainability conceptions, contexts and/or applications.

Given our earlier discussion about sustainability as a pluralistic concept, we see value in exposing students to an array of different ways of conceiving of this complex, abstract concept. If the aim is to expose students to a broad range of sustainability conceptions, we would advocate that sustainability be infused throughout the curriculum and responsibility for its teaching be shared broadly across the academic staff complement. That is, we advocate jumping straight to the infused model for incorporating new fundamentals, rather than the usual approach of extraction and specialisation, familiar from early efforts to teach communication skills for example (Mitchell, 1994). For this approach to be successful, the notion that variation and plurality are acceptable must be explicit. This approach could maximise students exposure to some of the variation in academic sustainability conceptions, and might also demonstrate how the concept can be flexed to address broader issues relevant to a range of disciplinary pursuits. We view this approach of infusing sustainability throughout the curriculum and exposing students to an array of different ways of understanding and actioning sustainability as a first step towards engineering education for sustainability.

A next step might be the active engagement of students in applying these various ways of conceiving sustainability, and critiquing the outcomes. This would represent a move away from a teacher-centred/passive student approach (Prosser and Trigwell, 1999) and towards learning in which the students' involvement and engagement with the concept and application of sustainability was of primary importance. During students' critique of outcomes, academics would have the opportunity to explicitly address the crucial role of values and subjectivity in the application of sustainability to decision-making (and in decision-making more generally). This passageway into the complexity and uncertainty of context-driven, multiple stakeholder, multiple solution problem solving could offer valuable learning opportunities for both teachers and students, and would constitute what Lemkowitz (2002) described as 'intellectually responsible teaching of subjects with strong normative content…'.

Opportunities for capacity building

Having considered some of the implications of variation in academics' sustainability conceptions for student learning, we now explore another potentially useful reason for investigating the way that engineering academics construe the concept. Some commentators have suggested that part of the challenge of integrating sustainability and tertiary curricula is a lack of familiarity, amongst academics, with the concept and its application (Filho, 2000; Crofton, 1995). These authors suggest that building sustainability capacity within the academe should be a priority and they highlight three priority areas: sharing examples of the application of sustainability to problem-solving, broadcasting economic and other arguments in favour of taking a sustainable approach, and on stimulating reflection and discussion about the concept of sustainability. Our research suggests the latter offers a significant opportunity for capacity building.

One way of stimulating reflection and discussion would be to elucidate some of the variation in the way sustainability is conceived of by academics within a given Department or Faculty. Characterising and shedding light on this variation could contribute to capacity building in a number of ways:

- Generating more open, discursive, and possibly conflicting communication about sustainability by allowing that sustainability might mean different things to different people;
- Acknowledging the subjective (assumptions and values) in personal conceptions and textbook definitions of sustainability;
- Providing motivation for the reflective engineering educator to look into, challenge and further develop their personal sustainability conceptions through exposure to colleagues' conceptions;

- Resisting 'cultural closure' in which one or two conceptions of sustainability gain approval within the Dept./Faculty and become normalised, with alternative conceptions considered to be 'wrong'; and
- Providing a potential basis for developing a toolkit of multiple sustainability frameworks or perspectives with which academics could enrich the teaching and learning of sustainable problem-solving.

Concluding Remarks

Our aim in writing this paper was to highlight the existence and nature of variation in engineering academics' conceptions of sustainability, and to ruminate on some of the opportunities and challenges this variation represented for teaching sustainability principles, ethics and practice.

We described how sustainability might be seen as a pluralistic process, rather than a prescribed set of technologies or outcomes, and how understanding a range of different conceptions of sustainability offers great potential for facilitation of sustainable, context-driven decision-making processes. We also demonstrated the value of delving into engineering academics' sustainability conceptions. An exploration of the many and varied ways in which engineering educators conceive of the concept throws up some interesting opportunities for professional development, as well as for student learning.

In closing we would like to revisit our earlier snapshot of engineering educators' conceptions of sustainability. As a group, the engineering academics we have surveyed displayed a resounding breadth and depth of sustainability conception. This suggests that there is a payload of raw material for professional development toward greater sustainability teaching capacity within the academe, provided academics are able to create the space and freedom to explore their own and others' views of sustainability, and to trial innovative approaches to teaching this chameleon concept.

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Acknowledgments

We would like to thank the various engineering academics who have generously shared their views on sustainability with us.

Reinventing the Bicycle Wheel

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***Abstract**: Education in transport engineering traditionally has been forced to fit within the field of civil engineering. However, it has been an uncomfortable fit, as transportation affects a wide spectrum of fields of knowledge, not only different sub-fields of engineering but also the sciences, planning and design and the environment. More recently, links with health and social sciences have been recognised, as documented by the World Health Organisation and in the proceedings of the NSW Childhood Obesity Summit.*

As a result, there has been a paradigm shift in the planning and design of bicycle facilities, with significant increases in State and Local Government funding and a strong focus on the provision of high quality off-road transportation facilities. In NSW alone, the State Government has published a bicycle master plan (Bike Plan 2010) that involves the expenditure of $250 Million over 10 years across NSW. In addition, the NSW State Government is committed to build off-road cycleways when new roads are built, such as a 40km off-road cycleway adjacent to the Western Sydney Orbital.

The paradigm shift has created a void in transport engineering knowledge. There is a strong need to reinvent the bicycle wheel and plug the hole.

This paper provides an overview of the recent changes from a consulting engineer's perspective, using the bicycle wheel as an image to drive the curriculum beyond the traditional civil engineering focus. The planning and design of bicycle facilities necessitates an understanding of associated health, social and environmental issues. There are strong links with urban planning, design and (landscape) architecture. There is a need to provide all-inclusive design responses to address multiple problems in a complex social and natural environment.

***Keywords**: sustainable, bicycle, transport*

Background

Typically, a professional field is described as a slice of cake and each profession provides its own distinct contribution. Traffic engineering has traditionally fitted within the slice of civil engineering with strong connections to road building. As the profession matured, more emphasis was placed on the infrastructure planning aspects, the relationships between roads and the surrounding buildings and the transport impacts on the environment (Figure 1).

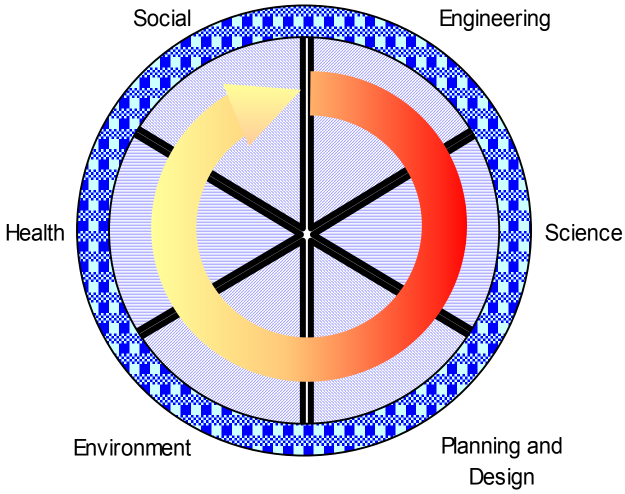


Figure 1: The bicycle wheel - individual segments have formed a whole

Despite the maturing of the profession generally, designing for the bicycle has changed little. The focus of the engineering profession remained on large infrastructure development, with only small contributions to bicycle infrastructure (Dorrestyn, 2003). For example, in many Council areas the implementation of bike plans consists of signposting a few selected bicycle routes with low traffic volumes and modest gradients, while there is limited construction of new pathways.

In future, however, there is a need for engineering design to incorporate the health and environmental benefits of cycling (and walking). Australian health authorities now recognise our sedentary lifestyle and our reliance on motorised travel as major ongoing public health issues (Sallis, Bauman, Pratt, 1998).

Similarly, social and environmental planners recognise that active transport (such as cycling and walking) is a key contributor to developing sustainable and socially harmonious communities. The engineering profession needs to be equally responsive to these social changes.

Of particular relevance in this context are the 2002 NSW Obesity Summit and the 1999 WHO Charter on Transport, Environment and Health and the findings are discussed in the following two sections of this paper.

Obesity Summit

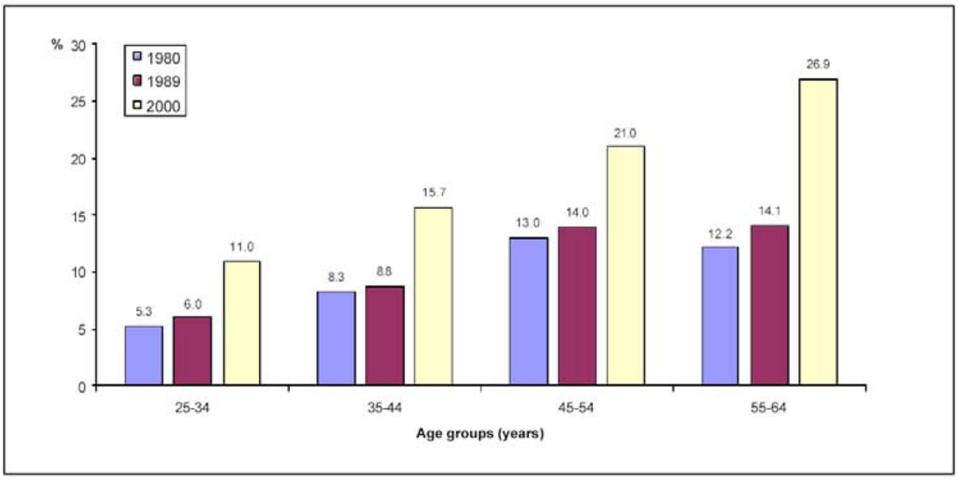
In August 2002, the NSW Premier called for a summit on childhood obesity to address increasing concerns from the medical profession. This section is an extract of the proceedings which is largely based on the background paper to the conference (NSW Childhood Obesity Secretariat, 2002) and Booth (2002).

The level of overweight and obesity in Australia has risen at an alarming rate in the last 20 years. In 1980 when the National Heart Foundation conducted the first large national survey of Cardiovascular Disease (CVD) risk factors they found that 48% of men and 27% of women aged 25-64 years and living in capital cities were overweight.

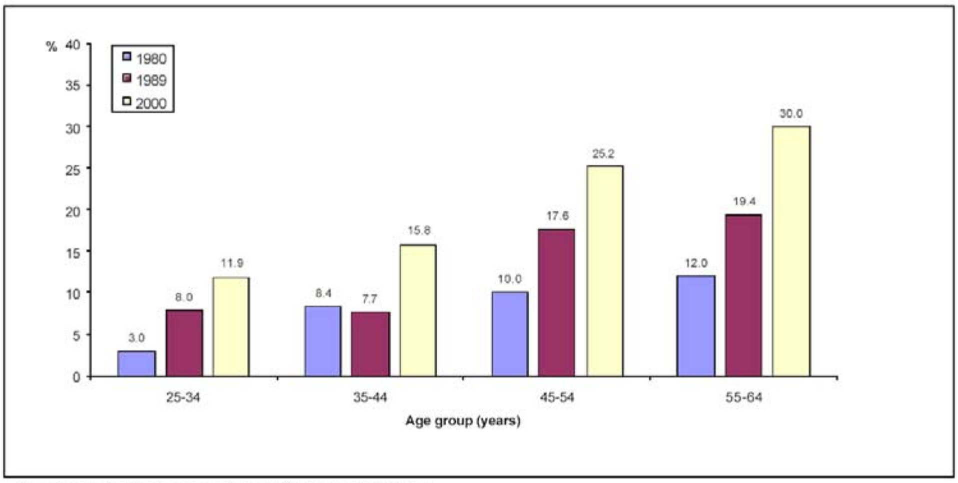
In the 2000 AusDiab study, the rates of overweight for the same population segment were 65% amongst men and 45% among women. Obesity rates rose from 7.2% in men in 1980 to 17.1% in 2000. For women the rise has been even greater, moving from 7.0% in 1980 to 18.9% in 2000.

More alarming is that the greatest proportionate rise in rates of obesity has occurred in the youngest age groups. Figure 3 shows that the level of obesity in the 25-34 year old age group more than doubled in men in the last 20 years whilst in women it quadrupled in the same age group.

A- Men



B- Women



Source: Report of the AusDiab Study 2000

Figure 3: Changes in prevalence of obesity in Australia 1980-2000 by age groups and gender

Almost every aspect of the way we live has the potential to contribute to reduced activity among our children, for example:

- Increased opportunities for sedentary recreation - eg television and video
- Increased demands for better academic performance - eg coaching and homework
- Increased car travel and less person-powered transport
- Increased concerns over child safety - eg stranger danger, traffic
- Fewer walkable destinations - eg shops and letter boxes

- Changes to the urban environment - more car and less pedestrian friendly
- Higher density living which do not consider the needs of young people
- Changes in architecture - eg homes with bigger "footprints"
- Personal injury litigation and reduced opportunities for physical activity
- More families with two working parents - "Go inside and lock the door until we get home"
- Parents working longer hours and are too tired and too busy to play
- Poor fundamental movement skills - as children participate less, they fail to develop these fundamental skills so want to participate less

While no single factor is the main cause so we need to consider and address all of the potential culprits, it is clear that infrastructure planning and design is a major influential factor on the way people go about their lives.

World Health Organisation

In 1999 London WHO Health Summit, the European Ministers for health, transport and the environment agreed that there were strong links between their three port folios. They resolved in a joint Statement, inter alia, that cycling and walking were key modes of transport that needed to be encouraged to the simultaneous benefit of these three areas (WHO et al, 1999).

Since 1999, the work has continued with the development of the Pan-European Program (THE PEP) which was adopted by the High-Level Meeting on Transport, Environment and Health at its second session in Geneva in July 2002 (UN, 2002). The PEP program consists of:

- Priority areas and actions for the tripartite work on transport, environment and health at the pan-European level
- A proposed institutional setting to carry out the work
- THE PEP Work Plan, outlining a number of specific and concrete activities, which could serve as examples of how tangible progress could be made in the priority areas.

The development of measures for promoting and improving safe conditions for cycling and walking is specifically referenced as a key element of urban transport management, such as the WHO "Guidelines for walking and cycling" discussed by Dora & Racioppi (2002).

These guidelines confirm that walking and cycling are increasingly being promoted as a means to reduce traffic congestion, air and noise pollution and the consumption of fossil fuels Figure 2). The following extract provides useful insights for engineering education and infrastructure development:

> *"Importantly, walking and cycling have also very relevant health implications, by reducing the risk of cardiovascular diseases, diabetes and hypertension, which are among the leading causes of death and disease in western countries, and their risk factors, such as obesity, particularly among children.*
>
> *"The United States Centre for Disease Control and Prevention for example, estimates potential savings from increasing physical activity of the most sedentary segment of the American population to be around $50bn in 1998.*

"Increasing walking and cycling as a means of getting from A to B, that is for transport, is not only good for our health. It has been proposed as a serious means to reduce traffic congestion, air and noise pollution [refer Figure 2] *in the urban environment and the consumption of fossil fuels. More cycling and walking for transport is believed to be one of the few feasible options to increase the levels of physical activity among the general population.*

"There is a concern that promoting cycling and walking for transport could increase traffic injuries. Even though this concern is frequently raised, only one assessment has been done to date on the balance of risks and benefits from increasing cycling and walking for transport. It found that the benefits were estimated to outweigh the loss of life through cycling accidents by 20 times.

"What is rather shocking is that partly because there is no agreement on the methods of how to take account of the health impacts of cycling and walking, these modes of transport have been excluded from present assessment of costs and benefits of transportation policies.

"There is an urgent need to develop the methods and gather the data sources which will make possible the assessment of the overall health impacts of increasing walking and cycling as part of transport and land use planning policies. This should allow the health effects of physical activity to become systematically a component of health impact assessments of those policies."

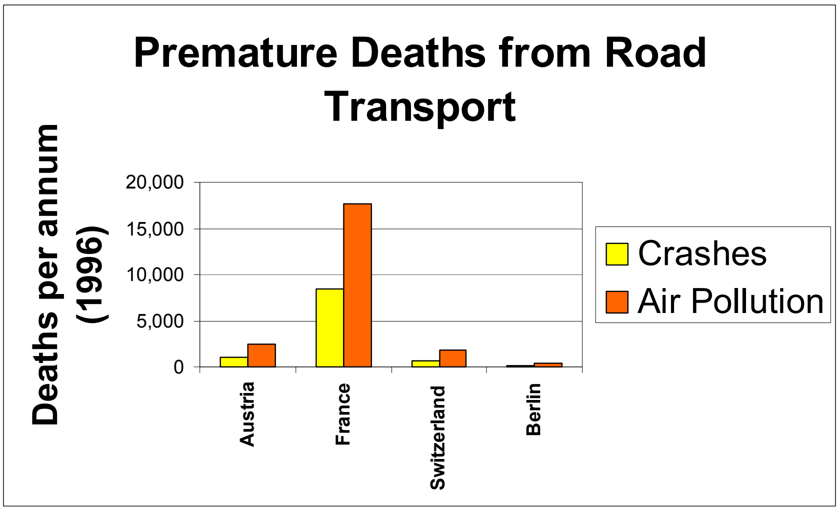


Figure 2: Premature Deaths from Road Transport

Budget Allocation

Funding allocation in NSW has increased from a mere $2M per annum for ad hoc facilities some 10 years ago, to an average of $25 million per annum including funding to support Local Government network development and implementation. The NSW Government has released its 10 year plan *Action for Bikes - Bike Plan 2010* for the provision of cycling facilities and the promotion of cycling. It is a $251 million program that will create an average 200 kilometres of cycleways across NSW each year. The NSW Government has made a commitment to establish high standard cycleways in conjunction with all new transport and road infrastructure developments, such as TransitWays, Parramatta to Chatswood Railway, Western Sydney Orbital Motorway and M5 East Motorway (Table 1).

Project	Description	Length	Cost
Liverpool to Parramatta Rail Trail	Largely off-road cycleway parallel to the Parramatta - Liverpool Railway	17 km	$12 M
Concord to Eastwood Rail Trail	Largely off-road cycleway along the Concord to Eastwood rail corridor (Figure 5)	8 km	$3 M
M4 Viaducts	Off-road cycleway underneath the motorway viaducts	6 km	$13 M
Bay Run Cycleway	Largely off-road cycleway with parallel jogging track along Iron Cove Bay	7 km	$7 M
Western Sydney Orbital	Fully off-road facility with 84 exclusive bridges and underpasses (BOOT project under construction)	40 km	$50 M
Fairfield to Homebush Bay	Off-road cycleway from Fairfield City Farm to Sydney Olympic Park	28 km	$8 M

Table 1: Some examples of current and recent bicycle infrastructure projects

This year the NSW Government has spent over $40 million on its bicycle program. The engineering profession needs to develop the capacity to translate this political will into high quality facilities that serve the active transport needs of their local communities.

The long term objective, surely, must be to achieve cycling levels similar to those in The Netherlands and Denmark, where some local governments record up to 30% of all trips made by bicycle. While per capita expenditure on infrastructure development and maintenance by these government agencies exceeds current local funding allocations, Australian governments have come a long way. However, sustained and increased infrastructure investment is required to meet national and international targets for health, the environment and transport that focus on increasing the modal share of bicycling (and walking).

Bicycle Infrastructure Provision

The provision of bicycle infrastructure has started to mature and there has been a sea change in the level of facilities, as contrasted by Figures 4 and 5. While it is sad to see that even today many bicycle routes continue to consist of merely “blue signs”, Australia has started to emerge as a potential leader in the development of “bicycle freeways”. These facilities consist of high quality “mini” roadways with grade separated intersections, that even the Dutch have only just started to consider. Although currently none exist in Australia, construction has commenced on the Western Sydney Orbital Cycleway, while planning has started for the North Shore Cycleway.

Figure 4: Early infrastructure for bicycles - a sign to lead the way

Figure 5: Recent infrastructure for bicycles - John Whitton Bridge, Meadowbank, Sydney, which is part of the Concord to Eastwood Rail Trail

Bicycle Network Planning

The planning of bicycle networks requires an integrated approach involving a range of professions. A good current example of such an approach is the public domain planning and design for a major urban renewal project. The multi-disciplinary team is led by a group of urban designers to establish design parameters for a broad range of urban development issues, including (Figure 6):

- Drainage system development
- Building set backs
- Cross section design
- Landscaping
- Tree planting policy
- Heritage protection
- Social planning
- Pedestrian network design
- Public transport routes
- Bus stop locations
- Site planning
- Through site links
- Art strategy
- Road network design
- Stormwater detention
- Open space planning

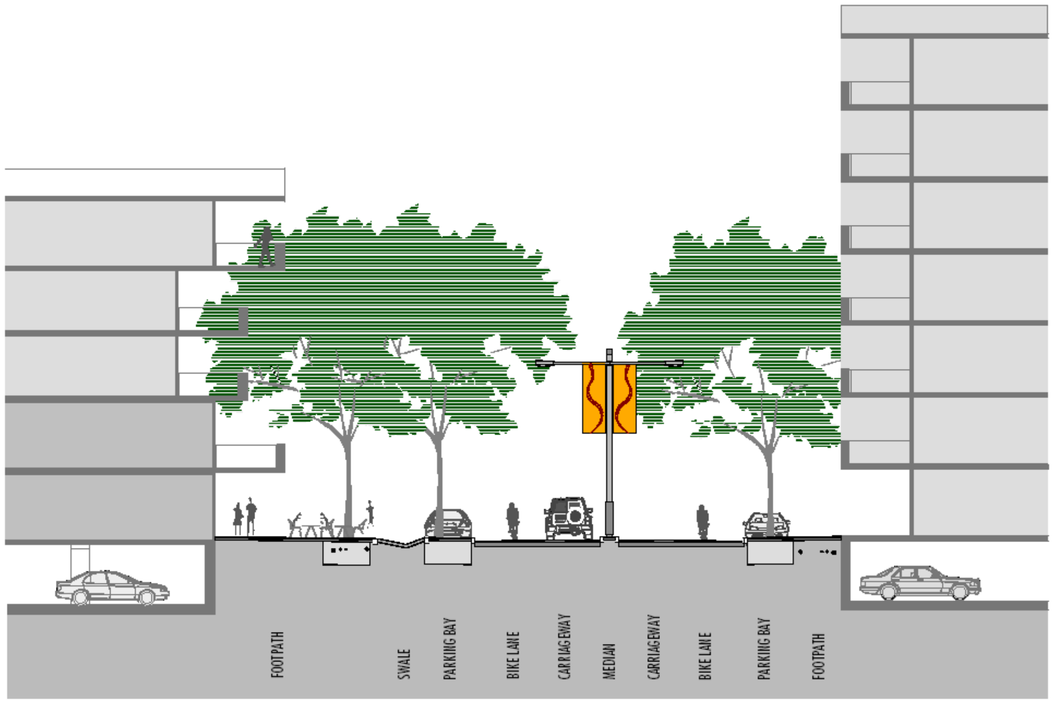


Figure 6: Boulevard design for urban renewal project

Curriculum Requirements

This paper has shown that there has been a dramatic change in both the underlying planning philosophy and in the provision of infrastructure for bicycles. There is a similarly strong need for engineering education to embrace the awareness of such negative outcomes and ramifications of engineering design. This awareness must be holistic and inclusive of public health and safety, personal well-being, social equity and much, much more. Similarly, there is a need for engineering education to incorporate the latest engineering design and evaluation techniques.

The Australian Bicycle Council is currently developing "Resource Kit" for use by engineering education institutions, which may include:

- WHO Guidelines for Walking and Cycling
- Austroads Australia Cycling - the National Strategy, 1999 - 2004
- Austroads Guide to Traffic Engineering Practice - Part 14, Bicycles
- Some Cycling References
- Some Relevant Cycling Website Addresses
- State Cycling Contacts
- NSW Cycling Guidelines
- NSW How to Prepare a Bike Plan - an easy three stage guide
- NSW Bicycle and Pedestrian Training Course Manual
- TransportNSW Sydney Cycling Data
- NSW Action for Bikes - Bike Plan 2010
- Cycling assignment descriptions and data
- List of cycling research opportunities for Masters and PhD theses.

The development of this resource kit has been endorsed by the National Committee of Transport of the Institution of Engineers, Australia and is planned for release later this year.

The following university and TAFE programs could consider including all or some of the information from the "Resource Kit" into their curricula:

- Civil engineering
- Highway engineering
- Environmental engineering
- Local government engineering
- Project management
- Asset management
- Town planning
- Urban design
- Landscape architecture
- Civil engineering drafting
- Specialist short courses transport planning, traffic engineering, etc.

Conclusion

Over the last decade there has been a significant increase in the level of investment in bicycle infrastructure. This infrastructure has been funded, planned and constructed by the 3 levels of Government (Commonwealth, State, Local Government). In addition, there has been a marked change in the design requirements for bicycle infrastructure, driven by an increased awareness of the health and environmental benefits of cycling (and walking). Improved access to the cycling and walking networks was a key issue at the 2002 NSW Obesity Summit as well as the 1999 WHO Charter on Transport, Environment and Health. To be able to meet these new challenges, professional engineers, planners and designers now require the skills to better integrate cyclists in road design, transport planning and urban development. The Australian Bicycle Council is currently seeking to redress this issue by working with tertiary institutions to include bicycle related design topics to undergraduate and postgraduate courses.

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Acknowledgements

I am grateful for the assistance and encouragement provided by Rolf Lunsmann and John Grinsell, NSW Roads & Traffic Authority; Paul Magarey, Acting Chair, Australian Bicycle Council, Department of Transport and Regional Services; and Kym Dorrestyn, Dorrestyn & Co Pty Ltd. Without their perseverance, this paper would have remained a mere thought.

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Abstract: *This paper investigates options for incorporating 'global sustainability' matters into RMIT University's undergraduate engineering degree programs. The project has been supported by the Institute for Global Sustainability at RMIT and the Faculty of Engineering. It reports on findings from interviews conducted with a number of employer representatives, on capabilities relating to sustainability that they saw as desirable in engineering graduates. On the basis of interviews and the Institution of Engineers Australia's engineering graduate attributes, a number of graduate capabilities relating to sustainability are recommended for RMIT engineering degrees. We propose that three thematic streams be run over the four-year engineering programs to develop these sustainability capabilities in graduate engineers. These themes are sustainable engineering principles and practice, social shaping and assessment of technology, and sustainable design.*

Keywords: *sustainability, engineering graduate capabilities, social shaping and assessment of technology*

Introduction

There is increasing interest in sustainability within governments in Australia at federal, state and local levels. In the private sector too, more and more corporations are adopting sustainability as a key objective of corporate governance, and practicing triple bottom line – social, environmental and financial – accounting practices in reporting to their boards, shareholders and the general public. The business case for sustainability is becoming increasingly accepted in the corporate world. Universities need to ensure that their graduates are well equipped to handle these demands.

This paper has been prepared as the primary outcome of a three-month project to investigate options and to assemble relevant information and other resources for incorporating 'global sustainability' matters into RMIT University's undergraduate engineering degree programs. The project is a component of the Faculty of Engineering's Program Renewal process and has been supported by the Institute for Global Sustainability at RMIT. The paper draws on two discussion forums held for interested staff from the Faculty of Engineering at RMIT, and interviews with representatives of several organisations that have addressed the question of desired capabilities of engineering graduates relating to sustainability.

Previous Work on Sustainable Engineering Education

There is a growing body of work in Australia and internationally on incorporating sustainability into education generally and into engineering education in particular. This work has been reviewed by Carew and Mitchell (2001). Here we briefly examine some examples.

The University of Technology Sydney has been working since 1998 to incorporate sustainability-related content, understanding and skills into its engineering degrees. The Institute of Environmental Studies at the University of New South Wales (2002) has produced a booklet offering broad assistance to academics in teaching global sustainability matters, focusing on how to engage students in activities and thinking that impact on sustainability. At RMIT, Roger Hadgraft (2002) advocated "inclusive teaching that recognises four learning styles and stages: understanding the problem in its context, theory, application and new possibilities". He suggests more emphasis on project-based and problem-based learning.

The Institution of Engineers Australia in collaboration with CSIRO, the Barton Group and a number of other organisations initiated the "Natural Edge Project" in 2002 to develop a 250-300 page resource book and associated web site to be entitled *Towards a Sustainable Future: Business Opportunities, Innovation and Governance in the 21st Century*. The project seeks to examine key sustainability issues and ways forward from a business/innovation perspective, with a focus on the most cost-effective best practice in the Asia Pacific.

Sustainability Capabilities Sought by Employers

Interviews

Interviews were conducted with eight senior personnel working in areas dealing with sustainability and sustainable development in industry and government, to gain an indication of the capabilities relating to sustainability that they saw as desirable in engineering graduates. Views were also obtained from a presentation by a senior manager of a large company to the second Sustainable Engineering Forum at RMIT convened in November 2002. Interviewees were selected using the RMIT Institute for Global Sustainability's list of industry contacts. All responded enthusiastically to the request to participate in the project. Of the nine people whose views were canvassed, six worked for large private corporations, one for CSIRO, one for a State Government department, and one for a State Government agency. Collectively their experience encompassed the mining, petroleum and associated processing industries, manufacturing industry, transport, energy and water supply, and forestry.

The group interviewed was small, and hence was not representative of the entire population of organisations employing graduate engineers. Particular limitations were the following:

- Resource-based industries were strongly represented;
- Only two representatives from manufacturing were interviewed;
- No consulting engineers were interviewed;
- All representatives were from large corporations and large government departments, and none from medium and smaller organisations;
- Only senior personnel in the organisations concerned were interviewed.

Nevertheless, much useful qualitative information and ideas on desirable 'sustainability' capabilities in engineering graduates were obtained from the interviewees. The main points to emerge from the survey are described next. In must be stressed that because the research is of a qualitative nature, no quantitative conclusions should be drawn from the data presented.

Main trends affecting response to sustainability

All interviewees regarded sustainability as an issue of considerable and growing importance, and one that should receive prominent coverage in all undergraduate engineering programs. They identified trends in industry and the broader environment that will be critical in shaping the way sustainability issues are understood and dealt with over the next five years.

A key trend alluded to was pressure from the public, and particular communities adversely affected by certain projects or technologies, for social, environmental and wider economic impacts of these developments to be fully considered in company and governmental decision-making (mentioned by 8 out of 9 interviewees). Those working in the mining, minerals processing and energy industries referred to the need to deal sensitively with the issues raised by indigenous communities and other local communities impacted by particular projects.

Most interviewees also noted changes within their organisations, including:

- making sustainable development – embracing economic, environmental and social dimensions – a central part of a company's mission (mentioned by 4 interviewees);
- responding to the climate change issue by reducing greenhouse gas emissions and shifting to renewable energy sources (4 interviewees); and
- taking greater responsibility for stewardship of a resource or product throughout its lifecycle even if they are directly involved in just part of that lifecycle (4 interviewees).

Desirable organisational attributes to deal with sustainability

Organisational attributes to deal successfully with the sustainability issue that were most frequently nominated by interviews were:

- to engage sensitively and constructively with the communities in which an organisation operates in order to secure their acceptance of a project (7 interviewees);
- to practice sustainability as an integral part of being a good corporate citizen with a good reputation with customers and the general community (5 interviewees).

Sustainability initiatives being taken

Initiatives being taken by organisations in response to the challenge of sustainability and sustainable development included:

- Adoption of company policies with sustainability objectives – social, environmental and economic – and performance targets relating to these objectives that are publicly reported;
- Calculating and trying to improve the ecological footprint of a company;
- Programs to raise staff awareness of and skills in dealing with sustainability;
- Addressing social, environmental and broader economic (as opposed to internal company financial) issues right from the conceptual, design and planning stages of a project;
- Designing products that contribute to sustainability;
- Introducing new or reengineering existing processes to achieve greater sustainability;
- New processes to consult local communities on developments that affect them;
- Introduction and implementation of environmental management systems.

Desirable engineering graduate capabilities relating to sustainability?

The central question of the interviews was the following:

> *Reflecting on the discussion so far, what values, understanding, knowledge and skills will forthcoming graduate engineers require to assist their organisation deal successfully with sustainability/sustainable development?*

In response, the graduate capabilities relating to sustainability most commonly referred to by the interviewees were as follows:

- Ability to assess and evaluate the importance of social, environmental and economic (as opposed to simply internal financial) impacts of a project, technological development, new process or product, using a holistic systems approach, with a scope encompassing all communities and natural resources affected. (All interviewees mentioned this to some degree.) Specific techniques mentioned included use of triple bottom line, lifecycle costing, determination of ecological footprints, and environmental impact assessment.
- The skills to communicate, listen, negotiate, resolve conflicts and work harmoniously with communities affected by the activities of the organisation. (Mentioned by 8 interviewees.) Such communities need to include indigenous communities both in Australia and possibly developing countries in which Australian-based organisations operate. Hence, basic understanding of and skills in cross-cultural communication and relationships are needed.
- Ability to engage in 'sustainable design' – of production processes, products, plants and other facilities, technologies, and projects – so that social, environmental and economic sustainability criteria guide the design process right from outset, and the maximal sustainability outcomes are obtained. (All interviewees mentioned this.) A number of the interviewees referred in particular to the need to encourage engineering graduates to "think outside the square", to have the confidence to innovate and depart from the traditional technical solution pathways, in the sustainable design process.
- Understanding of, and personal commitment to, the principles of sustainability and sustainable development, including the ethical foundations of these concepts, and the ability to exercise considered judgments based on these principles in real-life situations. (Mentioned by 6 interviewees.)

In addition, more specific 'sustainability' capabilities were mentioned in passing by some interviewees as desirable: knowledge and ability to develop environmental management systems, understanding of the principles of industrial ecology, cleaner production, and expertise in renewable energy technologies. However, the foregoing are clearly just a small sample of a much larger complete listing. Within each engineering discipline there are many specific capabilities relating to sustainability that are desirable for graduates to possess.

Deficiencies in graduates relating to sustainability

The interviewees referred to a number of deficiencies in graduate engineers (pertaining to sustainability but also applying more generally). These included:

- A too narrow focus on technical solutions, with consequent failure to take adequate account of social, environmental and economic/commercial implications, particularly at the early stages of a project. In other words, they often 'do not see the bigger picture'. They tend to be project-centred rather than whole-system oriented.
- Reliance on standard solutions to standard problems, and lack of confidence in taking new paths that may lead to innovation and major rather than incremental gains in sustainability.

- Insufficient skills in communicating concisely, clearly and persuasively to senior management or a non-technical audience, to gain approval and support for their proposals. One interviewee made the interesting point that engineers do not spend enough time on the front end of their report, the executive summary and recommendation for action, which is the critical part that senior management will actually read and use in deciding whether to approve the recommendation. They tend to be more concerned that the report 'passes the weight test' and is packed full of facts and figures.

Suggested 'sustainable engineering' learning activities

The interviewees were asked to suggest some learning activities that could help undergraduate engineers develop the sustainability capabilities. Some of their responses included:

- Get students out of the university, talking to practitioners, the community (including indigenous communities), seeing what is actually being done.
- Presentations from representatives from industry, environmental organisations, indigenous peoples' organisations.
- Use, case studies of actual projects showing technical, social, environmental and economic problems arose and how they were dealt with. Ask students to develop plan of action to see that these problems did not occur in the next project of this kind. Encourage the search for innovative solutions. Develop case studies in collaboration with companies or government organisations that work in this area. Involve company, government and/or community representatives in critiquing the solutions proposed by students.
- Student involvement in team projects – some involving students from non-engineering disciplines – to develop innovative solutions to problems relating to sustainability, with the aim of maximising the social, environmental and economic outcomes in a manner that was acceptable to the communities affected. The ability to work effectively in a team environment was a common theme in the interviewees' responses.

The IEAust Graduate Attributes and Sustainability

The relevance of sustainability in engineering education has been recognised for some time. The Institution of Engineers Australia (IEAust) published the findings of an extensive review of the future of engineering education in Australia (IEAust, 1996). The review identified that successful graduate engineers would increasingly require both in-depth technical competence and a broader set of attributes or capabilities that included sustainability. The IEAust now requires that engineering graduates develop the following generic attributes:

a) ability to apply knowledge of basic science and engineering fundamentals;
b) ability to communicate effectively, not only with engineers but also with the community at large;
c) in-depth technical competence in at least one engineering discipline;
d) ability to undertake problem identification, formulation and solution;
e) ability to utilise a systems approach to design and operational performance;
f) ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member;
g) understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development;
h) understanding of the principles of sustainable design and development;
i) understanding of professional and ethical responsibilities and commitment to them; and
j) expectation of the need to undertake lifelong learning, and capacity to do so. (IEAust, 2002, p. 14)

Clearly all of these attributes embody sustainability aspects to some degree, while attributes (g) and (h) have a particularly strong connection to sustainability. As part of its BEng Program Renewal Project, RMIT University has elaborated upon each of these engineering capabilities, in reference to engineering education in the RMIT context. We have ourselves further elaborated upon the sustainability aspects of each of these capabilities. For space reasons, this work is not included here, but is fully described in Andrews (2003).

Engineering Graduate Capabilities Relating to Sustainability

On the basis of the engineering graduate capabilities proposed by the employer representatives interviewed (section 3), and the sustainability aspects of the Institution of Engineers Australia's required engineering graduate attributes (section 4), we have recommended the following highest-level graduate capabilities relating to sustainability are recommended for RMIT engineering degrees:

- Understanding of, and commitment to, the principles of sustainability and sustainable development, including the ethical foundations of these concepts, and the ability to exercise considered judgments based on these principles in real-life situations.
- Ability to assess and evaluate the importance of social, environmental and economic (as opposed to simply internal financial) impacts of a project, technological development, new process or product, using a holistic systems approach, with a scope encompassing all communities and natural resources affected.
- The skills to communicate, listen, negotiate, resolve conflicts and work harmoniously with impacted communities.
- Ability to engage in 'sustainable design' – of production processes, products, plants and other facilities, technologies, and projects – so that social, environmental and economic sustainability criteria guide the design process right from outset, and the maximal sustainability outcomes are obtained.

Sustainability and Engineering Program Structure

Overall Architecture

It is proposed that three thematic streams be run over the four-year engineering programs to develop the proposed sustainability capabilities in graduate engineers:

- *Sustainable engineering principles and practice*, which would address directly the first sustainability capability, 'understanding of and commitment to sustainability principles', including their ethical foundations, the meanings of sustainability and sustainable development, and the use of these principles in practical decision making and judgments.
- *Social shaping and assessment of technology*, which would focus on the social (including economic, political, organisational governance, and cultural) processes by which decisions on technological development are made; the various techniques available for integrated social, environmental and economic assessment of technologies and projects; the business case for sustainability; and involvement of affected communities in impact assessment. This stream would develop both the second ('social, environmental and economic assessment') and third ('communication and negotiation skills') sustainability capabilities.
- *Sustainable design*, relating mainly to the fourth capability, 'design from the outset to achieve optimal and balanced social, environmental and economic outcomes', but also providing further opportunity to develop the third capability by engaging potentially affected social groups in the design process.

A significant portion of the total content of each of these three sustainable engineering streams will be applicable to all engineering programs, since they deal with principles (ethical and technical), understanding and knowledge, and skills and techniques relating to sustainability that are desirable for all engineers to have. The remainder of the content in each stream will preferably be specific to the various engineering programs, so that the practical relevance of the content to their chosen discipline is manifest to students. Hence there would be clear advantages in terms of ensuring consistency in curriculum, and economies of scale in curriculum development, if the portions of the three streams applying to all engineering programs are developed as a common component.

A considerable part of the first two proposed sustainable engineering streams in particular – 'sustainable engineering principles and practice' and 'social shaping and assessment of technology' – can be seen as providing the broader context in which professional engineers operate, and developing in them the values, understanding, knowledge and skills they will need to perform their professional roles successfully. The third stream, 'sustainable design', however, is more appropriately located as part of the core of each engineering program, given that it will involve innovative technical design and planning activities to achieve beneficial social, environmental and economic outcomes.

In the following three sections we sketch a possible scope of each of the proposed sustainable engineering streams. In describing these scopes, we are more concerned here with giving an idea of what the streams will cover, than with the way in which they will be taught and learnt.

Sustainable Engineering Principles and Practice

The objectives of this stream would be to:

- Explain why many current trends in Australia and globally are unsustainable socially, environmentally, and economically, including from perspective of individual businesses;
- Provide students with an understanding and knowledge of the principles of sustainability and sustainable development;
- Stimulate debate among students as to what sustainability and sustainable development mean, and what should be done to achieve these aims, so that they develop their own goals and commitments to action in these areas;
- Create learning situations in which students gain practical experience in making decisions and judgments based on sustainability principles;
- Demonstrate that sustainable principles and practice are integral to the role of the engineer, to good corporate governance, and to best business practice and outcomes.

Social Shaping and Assessment of Technology

The objectives of the social shaping and assessment of technology stream would be to:

- Provide students with an understanding of the social processes that 'shape' the development and deployment of technologies;
- Explore the history of selected technologies and projects to discover why certain unsustainable impacts arose, how they might have been avoided, and the lessons that might be learnt for effective and responsible corporate governance in the future;
- Familiarise students with a variety of techniques to assess impacts of technological developments and projects in social, environmental and economic terms, using a holistic systems approach;
- Demonstrate how affected communities can be involved in the impact assessment and decision-making processes;
- Develop in students the skills to communicate, listen, negotiate, identify and resolve conflicts, and work harmoniously with impacted communities;

- Show how good corporate governance that involves impacted social groups in shaping a new technology or project can optimise social, environmental and economic outcomes, including the bottom-line financial performance of the organisation concerned.

Sustainable Design

The objectives of this stream would be to:

- Provide students with an understanding of the principles of sustainable engineering design and the opportunities for innovation these principles create;
- Allow students to gain practical experience in designing technologies and planning projects to optimise social, environmental and economic outcomes, and enhance overall business and organisational performance;
- Introduce students to design processes that integrate the analysis of social, environmental and economic impacts, and communication with affected social groups, into all stages from initial concept, to implementation and operation, and recycle and reuse.

Recommendations

On the basis of the research and consultation conducted within this project, the following provisional recommendations have been presented for further discussion by selected program teams during the Engineering Program Renewal Process in RMIT during 2003:

- Make 'Sustainable engineering', in the sense of using technical engineering expertise to achieve beneficial and balanced social, environmental and economic outcomes, and hence contributing to sustainable development, a central theme in all RMIT undergraduate engineering programs.
- Present sustainable engineering in three thematic streams over the four-year programs: Sustainable engineering principles and practice; Social shaping and assessment of technology; and Sustainable design.
- Embed sustainability principles, understanding, knowledge and skills in other engineering courses where relevant.
- Run focus groups with selected current engineering students and recent engineering graduates from RMIT to discuss their ideas on how teaching and learning of sustainable engineering might best be incorporated in future engineering degree programs at RMIT.

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Acknowledgements

We would like to thank the Institute for Global Sustainability at RMIT for funding this study and acknowledge the support for the Sustainable Engineering Project provided by the Faculty of Engineering at RMIT University.

Experience with Remote Access Laboratories In Engineering Education

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Abstract: *Early attempts to implement on-line laboratories for remote access have encountered significant problems including complex software that is expensive to maintain, the need for administrative support, and the difficulty of deploying new experiments when needed. Several groups have been developing frameworks for on-line labs that overcome these problems. Most have been motivated by the possibility of providing laboratory experiences for distance learning. This paper describes a framework developed at The University of Western Australia that aims, instead, to increase the participation of on-campus students in lab work, though it could also be used for distance education. The investment required has been less than 10% of the cost of some comparable frameworks that are not yet completed. We now have some evidence that our remote access lab system provides a cost-effective solution that can be sustained within normal operating budgets after the initial investment to build the system has been made. This paper also provides many comparisons with other remote labs reported in the literature.*

Keywords: *remote access laboratory, internet, engineering education, learning effectiveness, mechatronics.*

Introduction

Many remote on-line lab experiments have been reported in the literature recently (for a recent surveys see Faltin and Teichman 2002 and Ertugrul 2000). (Note that there are many reports of "virtual labs" where "virtual" means simulated. It is important to emphasise that this paper is entirely concerned with remote access to real equipment.)

From the first months of operation in 1994, our telerobot (Taylor & Trevelyan 1995) was used from time to time, on request, as a device to help with courses on robotics. One of the earliest examples of a purpose designed lab experiment system on the web was described by Henry (1996a, 1996b). Salzmann *et al* (2000) and Gillet *et al* (2000) describe an internet-accessible DC servo device and how it can be used to help with student learning. Shen *et al* (1999) and del Alamo (2002a,b) describe similar arrangements in which students can remotely test semi-conductor devices in web-enabled experiments. A further similar arrangement has been developed in Norway (Fjeldy and Jeppson 2001). Ferguson (1997), Röhrig and Jocheim (2001) and Lemckert (2001) and many others have worked specifically on distance learning applications of this technology. Qanser (2001) offers commercial software and hardware for web-enabled control system lab experiments, and widespread engineering packages such as MATLAB and LabVIEW have well-developed software tools.

What has been learned from these pioneering efforts? Few of the early pioneering web sites are still in operation, or even show signs of recent developments. In terms of academic papers there was a surge of interest between 1994 and 2001, and the pace of development has slowed since then. The telerobot site is the only one of these to have continuously operated throughout this period. The UTC web lab (Henry (1996a) has operated since 1995 but considerable efforts have been required for maintaining a modest system. Operating and maintenance costs have been significant: special purpose hardware-related software has been a major impediment to the maintenance of several projects. Maintaining software capabilities through significant operating system, computer hardware and user software upgrades has taken significant resources and is cited as an issue of concern by most authors.

High software investment and maintenance cost has not discouraged further development efforts, however. Several new remote labs are under construction at the time of writing, particularly in Western Australia, the USA, Germany and UK (eg Böhne *et al 2002,* Schäfer *et al* 2002). The UWA system is being extended, and the MIT iLab project is being re-implemented in a Microsoft .NET framework. Most current projects have devoted more resources to a remote lab framework: a set of tools that enable many different remote labs to be deployed without large additional investment in software and expertise. At the same time, the ready availability of commercial software has enabled many smaller institutions to set up remote labs on an individual basis (e.g. Senese et al 2000).

The relatively small number of working systems and the slow rate at which this technology is progressing reflect some significant problems with early implementations. The problems appear in the form of high installation, operation and maintenance costs. Some of the underlying causes are:

- Cost of maintaining the system to keep up with hardware, operating system, internet service provider and browser technology changes.
- Complexity of technological components and of integrating a working system.
- Lack of administrative support for large classes.
- Need to deal with unreliable internet connections.
- Need for collaborating users to be able to work together.
- Difficulties with integrating on-line lab experiences into conventional courses.

Remote Access Labs – Design Issues

In 2002 we commissioned a comprehensive internet framework for remote access labs that aims to overcome these problems (Trevelyan 2002). The experience of the telerobot project (Dalton 2001) contributed a reliable system design which became the basis for a new system built in the LabVIEW programming environment.

MIT are currently commissioning another framework with the help of substantial sponsorship from Microsoft (del Alamo 2003). While the design has many similarities to the UWA framework it is based on systems engineered with .NET and links to some other Microsoft developments in campus software. Similar frameworks have also been developed at EPFL (Geoffroy *et al* 2001), the Open University (Schäfer *et al* 2002) and Hannover University (Böhne *et al* 2002). Some of the budgets are large: the Open University and MIT projects will cost around US$2,000,000 each.

There is now enough experience with remote on-line labs to discuss some of the main issues in general terms. The issues include:

- Learning aims: supplement to hands-on labs, distance education, providing for flexible learning styles or sharing expensive equipment resources.
- Institutional aims: single demonstration facility, support for on-campus students, support for selected other institutions, or broad access.
- Lab experience: fast batch experiment with user settings, queued batch experiment with user settings, interactive experiment with on-line user interaction, data acquisition experiment with access to historical data, or programming experiment.
- Telepresence: instrument and chart display readings, still images (low bandwidth), sound, and/or real time video (high bandwidth).
- Access control: single user or collaborating team access, queue management, timetabling and scheduling.
- Administrative support: single task or multiple tasks, course management, student enrolment.
- Software configuration: single or multiple experiments, single or multiple servers, broken connection handling, student data management.
- Investment and expertise needed to extend system.

Simulation or Real Equipment?

One of the most frequently discussed issues is whether a simulation can serve as well as a real experiment, particularly when the experiment is conducted remotely. How can the remote user distinguish real equipment from a simulation, particularly if the user is a student who has little experience with real equipment? In 1995 I demonstrated the telerobot to a class at the University of Toronto and a graduate student asked which computer graphics package we had used to create the blurry still images that were actually obtained from our cameras and transmitted across the internet. He could not accept that there was a real piece of equipment there!

Böhne *et al* (2002) summarise a survey of 19 remote labs: "you often do not get the feeling of being in the lab or of working with real devices. It is hard to tell if the experiment is being performed in reality or just faked by prerecorded pictures and videos generated by simulation". In reality, one has to rely on the belief by students that the equipment they are controlling is real. It helps if they can see the equipment from time to time as they pass the lab where it is physically located.

The continuing low bandwidth limitations of the internet impose strict limits on the extent to which images and sounds can be faithfully transmitted to a remote user. Real time video of reasonable quality is usually not feasible.

Several telerobot users who have visited the lab after using the robot remotely have remarked that the lab arrangement is somehow different to what they imagined. Because of this, we expect that it is beneficial if students have seen and preferably had the chance to use the equipment in the lab, though we have not yet evaluated this formally. One reason for developing the electric iron experiment is that all students would have an iron at home (though our students never seem to actually use their irons!).

Böhne *et al* (2002) propose that real hardware has limitations that emphasise constraints faced in real life situations. Unlike a simulation, real equipment cannot be reset to an arbitrary starting condition: a simulation application on most computers can be "killed" and restarted almost instantly. It can be difficult to create a simulation: the domestic electric iron described later is very simple in principle but would still be a significant challenge to simulate faithfully (eg see Hites 2002 concluding comments). A further difference is that a real device is imprecisely known, and we cannot vary its characteristics or speed up its response. This means that experimental procedures with a real device are not likely to be the same as explorations with a simulator.

Of course, the advantage of a simulation is that students do not have to wait: they can work with a simulation running on their own computer. However, the fact that students have to queue for a real piece of equipment (if it is being used by someone else) emphasises the reality for them.

Lindsay and Good (2001) reported an unusual experiment in which they compared hands-on lab learning, learning from a simulation and learning from a remote lab. This work has continued but the final results are still to be published. This pilot study was inconclusive, but seems to indicate that when it comes to specific material relevant to a particular lab it is hard to distinguish the results. Hites (2002) concluded from student feedback that remote labs are best used as a supplement for hands-on labs.

The Lab Experience

Lab exercises present a large range of different experiences. Many require extensive hand manipulation which would be too costly to provide remotely using telerobotics. However, since most engineering measurements can now be recorded electronically, it is possible to offer a wide range of lab experiences remotely.

We can consider the following kinds of remote experiments:

- Queued batch: the user sets parameters and transmits a command to begin the experiment. There is no user interaction during the experiment. Either the experiment happens so quickly that interaction is impractical, or interaction is undesirable, or is simply not provided for in the software.
- Real time interactive: the user can change parameters and observe results in real time. Here there are three limiting factors:
    - The network round trip time: the time taken for a command to be transmitted to the equipment and the initial response to arrive at the user's computer to be displayed – this is typically between 0.1 and 0.9 sec.
    - The network bandwidth may restrict the type of feedback available to the user, and the rate at which it can be displayed.
    - Streaming video or sound may be delayed by several seconds so that it can be displayed correctly at the user's computer.
- Real-time measurement (typically with archives of previously recorded data). In this kind of experiment there is no need for the user to set controls except, perhaps, to select the desired data characteristics. Time delays in transmitting the real-time data do not matter, but may differ between data and video streams.
- Programming experiment. In this kind of experiment, the user is expected to develop code for a programmable device. While working on the code there is no need to access the equipment. When ready, the code needs to be downloaded and then executed, possibly with some kind of user interaction.

The following sections present some current examples of remote experiments to illustrate this classification.

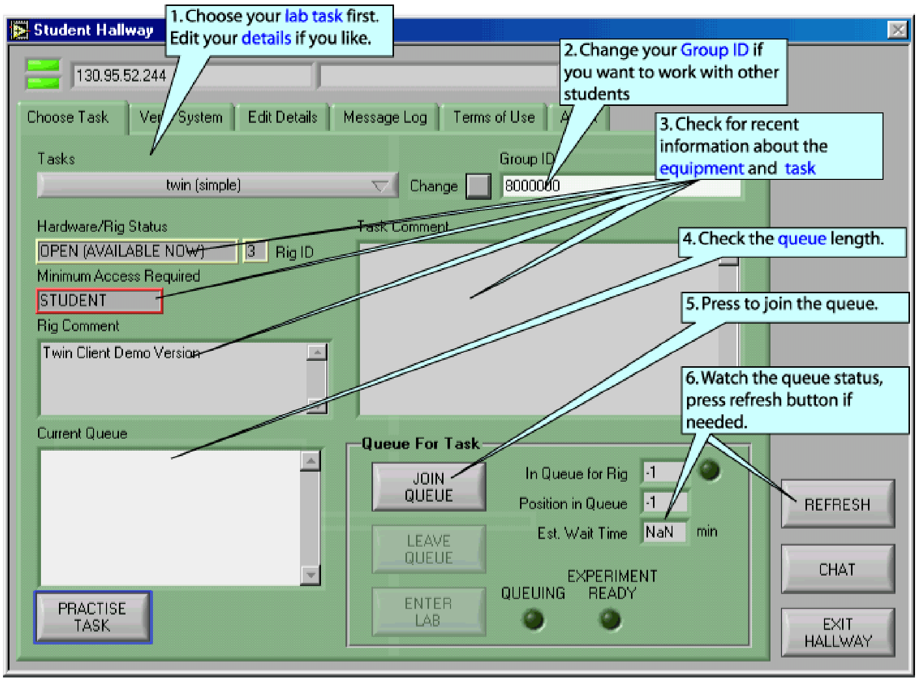

Figure 1: Typical hallway interface for students waiting to use the UWA system.

Instrumented Electric Iron

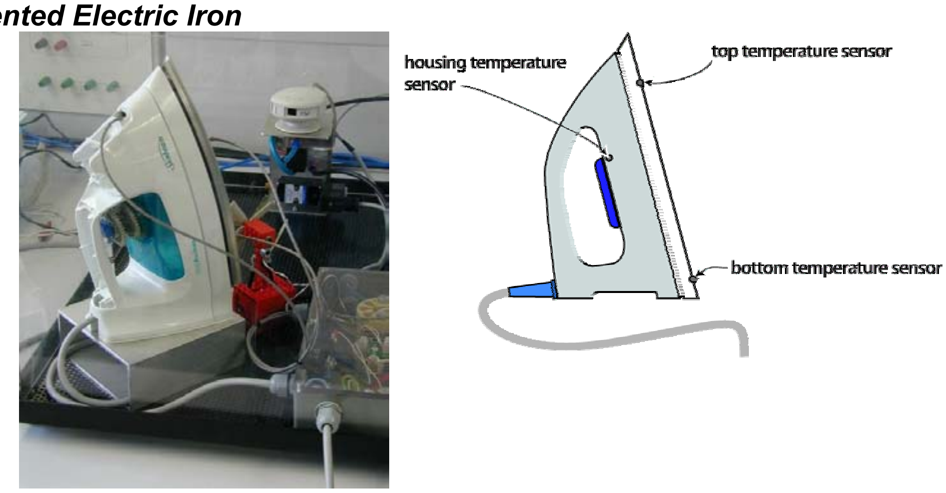

Figure 2: Instrumented remote access electric iron equipment at UWA

This experiment is offered currently at UWA. A domestic electric iron fitted with temperature sensors and a controllable jet of compressed cooling air, can be operated in several different ways:

- simple manual on-off control,
- pulse width modulated power control,
- feedback control.

The equipment can be used for several lab classes:

- Thermodynamics of a simple domestic appliance, heat transfer by convection and conduction.
- Modelling of a domestic appliance, from simple first order equation representation to finite element thermal modelling.

- Mechatronic discrete control and sensing.
- Control system theory applied to a simple non-linear system.

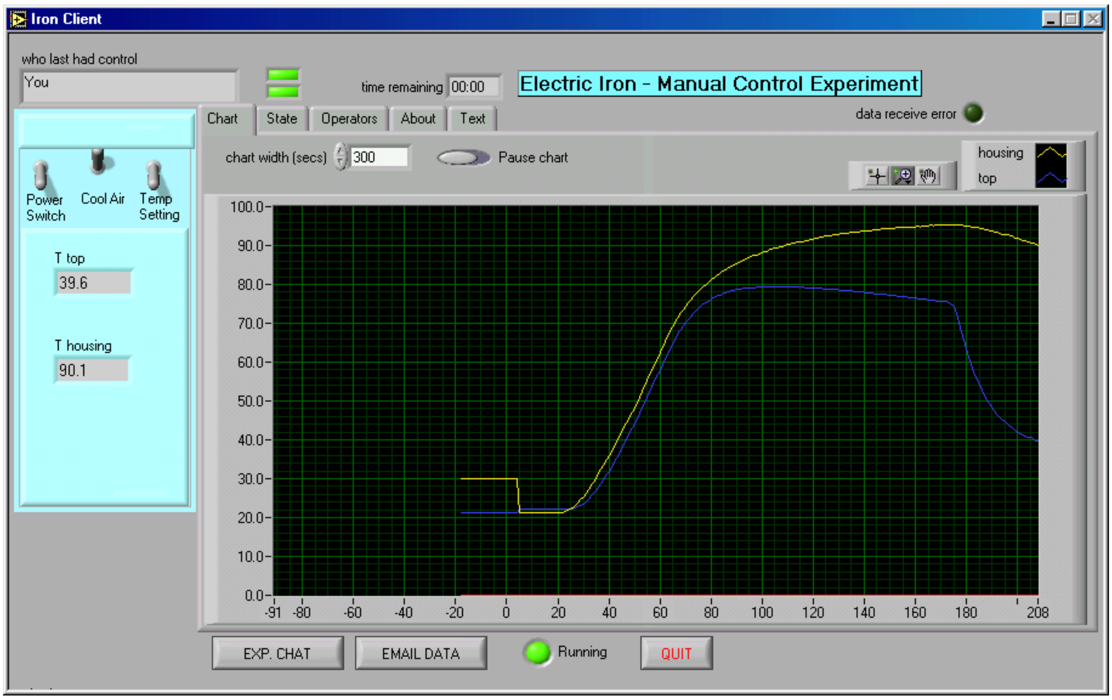

Figure 3: Typical introductory task control panel for electric iron experiment

The lab experience requires a student to set certain operating parameters and interact with the equipment for a time of between 5 and 30 minutes depending on the tasks to be performed. Since the appearance of the iron does not significantly change there is little value in providing a real-time image of the iron for the student user.

The equipment is inexpensive. However, the are several aspects of its behaviour that are subtle: these can present a significant challenge to undergraduate students. For example, when using the internal thermostat, the temperature at which the thermostat switches off the heating element decreases significantly aver the first 15 minutes after the iron is first switched on. This is not easy to explain, given that the thermostat is a temperature sensitive switch with well-defined switch on and switch off temperatures.

Torsional Vibrations

A servo motor excites low frequency rotational vibrations of two discs coupled by soft torsion springs. Students need to observe how different amplitudes and frequencies of excitation affect the motion of the discs. Data on disc motion arrives rapidly in real time (data is collected at 30 Hz) but students must observe the discs for several minutes at a time as transient effects last for up to two minutes.

An instrumental and chart display is sufficient to display the disc motion. While it is preferable that students can observe the discs directly using real-time video the data rate required means this is only feasible using broadband or local area networks.

Figure 5: Torsion Vibration remote access equipment at UWA: an example where high rate real-time data needs to be shown to the user.

Some Initial Evaluation Results from UWA

The UWA system has been in use since early 2002. Preliminary results suggest significant cost savings in comparison to other remote lab systems and two important learning advantages. Students can experience more operating time per week than in a conventional lab class. Also, students who are reluctant participants in a normal lab group (up to 40% of the class) can operate remotely without the fear of making an embarrassing mistake in front of their peers. We have also found that prior first-hand experience with the real hardware helps students to understand what they are doing without the need for a real-time video image of the equipment. This means that students can use the system over slow modem connections.

A further advantage is cost. The total investment in the UWA system so far is approximately AU$220,000 which is less than 10% of budgets for comparable projects at the Open University and the MIT i-Lab project.

There are three differences that help to explain why the UWA system cost is much less than the others mentioned.

First, cost-effectiveness has been a desired outcome from the start. For this reason we looked at several different software tools and concluded that LabVIEW was likely to be the most cost-effective. Similar conclusions have been drawn by Vilalta (2001) and Berntzen *et al* (2001) who also report more efficient operation with LabVIEW.

Second, we have worked towards a system in which new additions to the system could be built by undergraduate students in project work with modest supervision. All the equipment on the UWA system has been integrated by students, though some re-engineering by staff has been required to establish high quality templates for later students to follow.

Last, we have not attempted to closely integrate the system with the student record system on our campus. Class lists can be imported using spreadsheet text files, and students are permitted a degree of self-enrolment when appropriate.

So far, we have been able to administer the system and maintain the hardware using existing staff resources.

To evaluate the learning effectiveness of this system we offered third year mechanical and mechatronics engineering students an option to repeat part of the experiment they had performed in scheduled lab classes to improve their learning. Software for this particular lab was developed by a final year mechatronics engineering student who was also the teaching assistant supervising the lab classes. (Davies 2002)

These students were invited to use a remote lab task to explore aspects of controller tuning. The task required them to set given proportional, integral and derivative gains for a controller driving a large pointer in the lab, and measure performance parameters such as rise time and overshoot. The task was optional and set in the second last week of semester, so the relatively high number of students who attempted the task was very encouraging. The students were asked to answer an on-line questionnaire, and identified themselves by student number so that we could relate their responses to log file records.

67 students responded to the questionnaire, of which 62 of the students used the system. 57 students managed to operate the remote lab for more than 5 minutes. This attrition was due partly to inability to install or operate the software well enough to connect to the server.

Of the 57 students who used the system for significant lengths of time, the average total operating time was 21 minutes. Most users achieved operating times between 10 and 30 minutes, though these were often in short sessions. The maximum time that a student was permitted to reserve was 15 minutes. Most sessions were less than 15 minutes in duration. For early users, a fault in the system limited sessions to 5 minutes and this affected about two thirds of the class. This fault also caused some problems for users which limited the number of successful connections to the system.

Operating time reported by students	Number of students
Watched, did not operate	28
<10 minutes	8
10 – 20 minutes	14
20 – 30 minutes	5
30 – 60 minutes	6
> 60 minutes	5

Table 1: Operating times in scheduled lab class from survey

This result contrasts with the scheduled lab classes. 10 classes were scheduled for a total enrolment of about 112 students over a 4 week period. Attendance at the early classes was typically 6 – 7 students, and up to 15 students for the later classes. Although there was a booking system to limit attendance, in practice students forgot to attend earlier classes and so later classes were overcrowded.

Table 1 reports the responses by students to the on-line questionnaire. One of the questions they were asked was to recall how long they operated the equipment during the scheduled lab classes.

These results demonstrate that the remote lab has significantly extended the lab experience for most of the students in the class. Only 16 students (about 25%) operated the equipment for 20 minutes or more in the scheduled lab class. However, all except 14 students managed at least 10 minutes using the remote lab, and most managed more than this. Nearly all the students managed to complete the assigned task using the remote lab.

Other questions explored student preferences. We found that a significant number of students had difficulty installing the software in our computer labs, and at home. Installation CDs were made available but few students used them. A simple download and install procedure is needed. However, with more labs on the system, students would learn how to do this better. Most of the students said they preferred to use the real equipment if was available. When asked why they did not operate the equipment in the lab, most said this was because others were operating, or there was not enough time for their turn in the lab class. Some said they did not know what to do (10), or were afraid they would make a mistake in front of other students (6).

In another class, an on-line lab was made available for second year mechatronics engineering students to develop a simulation model of an electric iron. This exercise was conducted in the last week of semester. The students did not have to use the on-line lab because data from the lab was provided independently to the class, but extra marks were awarded for a simulation model that would work in cases other than the one supplied. Out of 50 students in the class, 21 students elected to use the on-line lab for an average time of 53 minutes (cumulative). Average session time was 16 minutes: the maximum possible reserved time was 15 minutes, but many students were able to achieve longer session times because they used the equipment at periods of low demand. Peak usage time corresponded to attendance at the University – 12 noon till 6 pm.

Unlike the position control experiment, most of the students had never operated the equipment before. Most had seen the equipment in the lab during other class activities.

Around 75% of all access to the system was from on-campus computer labs and 60% of these sessions were from our own computer labs where the software had been pre-installed. Interestingly, even though students could use the equipment from adjacent computers for much of the day when the lab was open, almost no students chose to do so. Had the system been used for larger classes with tighter deadlines, we could more students would have used the system from off-campus locations. Some students complained about having to download the initial installation files (12 Mbytes, mainly for the LabVIEW Runtime Environment), though this was also made available on CD-ROM. However, once the initial installation has been accomplished, each new lab client only requires a 1.5 Mbyte download. The electric iron experiment involved quite long operating times because it takes time to collect the required data. Students could happily work on other assignments while watching the temperature chart.

Even though they were free to do so, none of the students chose to operate with other students at the same time. We did not draw the attention of students to this facility. On at least one occasion a server fault enabled two students to operate the equipment at the same time accidentally. The students reported that “someone was hacking into the system”.

Conclusions

The total investment in the UWA telelabs system was approximately Au$220,000 including integration of the equipment described in the preceding sections. The cash outlay included computer and interfacing equipment for the equipment mentioned above, the core server software development contract and assistance with commissioning, student scholarships and some engineering supervision for designing some of the equipment. Staff time, university workshop time and student projects that are part of the teaching curriculum are not included in the cash budget. A minimum of one LabVIEW professional development system licence is sufficient for developing and operating the system at a cost of Au$3800 (approx): our investment included a full faculty licence at a cost of about Au$30,000 as LabVIEW has become popular in several engineering departments.

Most of the on-labs presented so far in the literature have been single demonstrations of the technical possibilities. Few have been systematically evaluated in terms of student learning effectiveness, and fewer still in terms of cost effectiveness. The enormous effort on software development has been justified in terms of the potential of this technology to broaden the educational experience. Some evaluation has been, and is being done currently, but it will still be some time before we can see whether there are real long term cost benefits.

Although it has taken three years to develop our on-line lab framework at UWA we are very happy with the results and it will become a standard part of our learning environment for students. While we yet to demonstrate overall cost-effectiveness gains, the initial investment has been much less than reported for similar efforts in other universities.

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Acknowledgements

This has been a research and development project supported by the Faculty of Engineering and Mathematical Sciences Faculty Initiatives Fund. The author would like to thank his colleagues and his students for their support, particularly Jan Baranski who engineered much of the hardware, Alex Le Dain of ICON Technologies who engineered the core of the software system in LabView, Sabbia Tilli, and my many students who have contributed and learned much in the process. Thanks are also due to reviewers who made valuable comments on the draft.

A Web-based Learning Module for the Design and Construction of Industrial Pavements

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Abstract: *The " Industrial Ground Slabs " topic was selected for development into an interactive computer module. The web based tutorial exercises comprise multiple- choice questions with multiple answers and visual image questions. Appropriate questions covering all of the structural design issues as well as construction detailing and methods of construction, are based on the lectures, digital video presentations and the site visit. The package encompassed structural design principles, pouring sequences, joint types and layouts, formwork and joint detailing, pouring methods, trowelling methods, surface finishes and tolerances, curing and sealants. Construction technology is an intrinsically visual discipline and structural design theory and principles must be contextually linked to construction practice. Slides, digital images and digital video from past and current construction sites are used during lectures to provide these links. The tutorial program developed has direct access to a database of construction images. The students have the ability to access and review all the lecture images and can view the full database of images in their own time, thereby strengthening the contextual links.*

Key Words: *Structural design principles, contextual links, virtual design management and construction studio.*

Introduction

The web based package was developed as part of a Virtual Design Management and Construction Studio (VDMCS) suite of projects. This paper overviews and highlights the key features of a web based interactive program / learning tool, developed for a third year " Structures and Construction 3A" subject. The paper discusses some educational theory surrounding the advantages and limitations of computer-based courseware as a learning model, and the development of a set of interactive web-based tutorial exercises and assessments.

The course's ultimate aim is to produce graduates that can become effective construction and project managers. There are a number of subsidiary objectives that can also be articulated which include:

- To link structural design principles with current construction practice
- To provide contextual information and links with real construction techniques
- Encourage the acquisition of the skills necessary to undertake construction projects
- To engage the students as active learners

Teaching Environment

The University of Melbourne offers undergraduate courses in Property and Construction as a single undergraduate degree and also as compulsory core subjects within a number of double undergraduate degrees including architecture, geomatics, commerce and law. The subjects offered must accommodate several discrete cohorts of students that may have different perceptions of the value of the subject to their needs.

According to Seracino, Daniell, Webster and Doherty (2001), “One of the greatest shortcomings in the training of civil and environmental engineers is the lack of real life practical experience upon graduation. The experience gained by visiting construction sites first-hand cannot be conveyed through lectures alone. Unfortunately, site visits amount to only a few hours in the academic career of a student and only a “snapshot” of an entire project is ever experienced.
The digital videos and images taken over many years can provide a viable learning alternative to site visits and comparisons from various sites can be made, thus providing a distinct advantage over a single site visit.

There are many difficulties in arranging site visits for students. For example, Kajewski (1999) suggested that large class sizes, tight time tables, busy site management, distant sites and site safety concerns have drastically curtailed such useful opportunities for a close-up appreciation of some construction processes. These restrictions necessitate alternative solutions and brought about the development of this package.

Ramsden (1988) contended that a contextual understanding of the problem is an important step in the learning process. However, teachers in construction management courses are increasingly having little ability to provide the students with an effective contextual experience in construction.

According to Beacham, Bouchlaghem, Seden and Sher (2000), construction is an intrinsically visual discipline. Many construction processes are underpinned by an understanding of how structures are constructed and how constituent components fit together. With very specific and precise questions in the tutorial system, and backing up with appropriate images, current design theory and construction practice can be placed in context.

Atkinson and Shriffen (1968) claim that an additional advantage of a self-paced learning approach is that it allows the learners to rehearse lessons learned which allows information that would normally slip from short term memory and be lost, to instead reside in long term memory. The web-based package allows students to work through the entire topic and repeat sections if necessary, all at their own pace in their own time.

The need to encompass a variety of teaching methods and adapt to cover differing learning modes is further evidenced by Walker and Vines (1997), who state that large group teaching presents difficulties when dealing with students from diverse backgrounds with varying levels English language comprehension as it tends to inhibit asking questions to clarify technical points or the nomenclature of building components. The package caters to the needs of varying student cohorts.

Background to Computer-assisted models and learning

Previous research has shown that computer-assisted models can provide a worthwhile addition to the teaching aids used in the undergraduate subjects, as indicated by Menser (2001). As an example, computer courseware provides many advantages over traditional teaching approaches, including, the ability to undertake the exercises at times convenient to the student, the opportunity to repeat the exercise a number of times, the ability to interact with the computer model, and the capacity to be used with large class sizes. Thus computer assisted learning approaches have a much greater flexibility and may provide a better learning experience.

In computer-based tutorial exercises, Menser (2001) showed that many factors impacted on the ability of the courseware's effectiveness. The adoption of computer-based tutorials can only be used for the practice of low-level skills; this is because although there are some standard feedback dialogues, lecturers bring an insight into how the student is approaching the problem. The face-to-face approach allows the personal intuition of the teaching to guide the student down the correct path. For instance, the authors said, "when students enter a wrong answer, it is usually wrong in a reasonable way…. Students found that they need to talk to lecturers about questions arising from the computer-based problem. Teaching needs enthusiasm and its effectiveness is dependant upon creating that environment".

Given these research findings, the web-based tutorials adopted a self-paced, convenient time approach utilizing the students' own computers. Interaction was incorporated through immediate feedback with scores and reasons for the correct answers.

Features of the Structures and Construction 3B Web Package

Selections
The first VDMCS screen directs the students to select one of four packages:
- Construction Methods and Equipment
- Structures and Construction
- Construction Cost Planning
- Management of Construction 3

Students at this stage may also select to go directly to the:
- Construction Image Database (details later provided)

Access
Having selected "Structures and Construction", the students Login name (their name from their student email address) and their Password are required to be keyed in. Only students currently enrolled in the subject can gain access to the web-based exercises under the University of Melbourne's "webraft" system. A matrix of questions in all sections allows the questions to be rotated for 6 years, without repeats. Students can practice in one section and be tested in another. (refer to delivery strategy below).

Assignment problems index
The lecture series on industrial ground slabs covered 4 x 2hour lectures, tutorials and a site visit. The tutorial questions followed the lecture content / series and students could then select from eight different exercises: The number of questions in each section are shown in brackets.

- Exercise 1 Design Principles (14)
- Exercise 2 Pouring Sequences (7)
- Exercise 3 Joint Types and Details (20)
- Exercise 4 Formwork and Joint Detailing (7)
- Exercise 5 Pouring Methods (10)
- Exercise 6 Trowelling Methods (9)
- Exercise 7 Surface Finishes & Tolerances (9)
- Exercise 8 Curing and Sealants (7)
- Total 83 questions

A series of multiple choice questions of varying difficulty under each of these exercises and areas, requires the student to have developed a reasonable level of understanding in most aspects of industrial ground slabs, from design and detailing through to construction.

The number of responses to correctly answer each question is indicated. If a student answers correctly on their first attempt, a mark for that question is given together with an explanation for the correct answer. If a student answers incorrectly on their first attempt, an “incorrect” response is indicated. The student is then permitted a second attempt. A second incorrect answer produces a zero mark, followed by the correct answer with an appropriate explanation.

This immediate feedback builds up their level of understanding as they progress through the exercises. The ability to complete these tutorial questions in their own time and at their own pace has proved to be quite successful in developing an reasonable understanding of this topic. This was as indicated by way of improved student results and responses to a similar hard copy written test and at the end of semester exam questions.

Sample questions from the 8 tutorial exercises

With 83 questions in total, covering 8 areas of design and construction, followed by the image questions; the tutorial package is quite comprehensive. A considerable amount of time was spent developing the 8 sections and the range of questions within each exercise to extract the important concepts and contextually place these concepts into real construction issues. The selection of corresponding answers was methodologically developed to require some in depth thinking and comparisons to be made between alternative answers. There are subtle and discrete differences between the alternative answers provided and the correct selection does take a considerable amount of time to correctly evaluate. To give the reader some indication of the typical questions and answers, a selected few have been provided below to give an indication of the question styles developed.

Design Principles:

Subgrade drag can be reduced by? (2 answers req’d)

(a) Providing one layer of polythene membrane under the slab
(b) Providing two layers of polythene membrane under the slab
(c) Not having thickenings in the slab
(d) Providing a thicker sand bed

(b &c) Two layers of polythene allows slab to slide easier. The sloping edges of thickenings restrict the sideways shrinkage movement of the slab, increasing drag

Pouring Sequences:
What are the disadvantages of large area continuous pours? (1 answer req'd)

(a) Shrinkage / crack control
(b) Need very long screeds to level the surface
(c) Difficulty to obtain surface tolerances
(d) Takes too long to pour the concrete
(b) Unless vibrating laser screeds are used, surface tolerances for large areas Can be difficult to achieve using spot levels.

Joint Types and Details:
What are the critical items to look for when dowels are used in a joint? (4 answers req'd)

(a) They are accurately spaced
(b) They are set up level
(c) They are aligned parallel with the long direction of the strip
(d) They are coated with grease / bitumen each end
(e) They are clean cut at the ends and not guillotine cut
(f) They must have transverse bars tied to them to hold the dowel bars in place during the concrete pour

(b,c,d &e) Dowels must be at right angles on plan and sections to allow free movement to occur. Coating the bars allows slippage. If ends are not clean cut, burs on end of dowel can bind the joint together.

Pouring Methods:
If a truss type vibrating screed is used during construction of a slab, do you need to use immersion / poker vibrators as well? (3 answers req'd)

(a) Only if the slab is post-tensioned
(b) Only close to the edges
(c) Only if the slab is steel fibre reinforced
(d) Only if the slab has steel reinforcing bars or fabric
(e) Only if there is a keyed construction joint.

(a,b&e) Vibrators required in post-tensioned slabs to make sure concrete completely encloses the ducts (underside). Edges of slab need to be smooth finished / free of voids to avoid bonding. Key joints ditto.

Trowelling Methods:
Several passes of the helicopters are required to obtain a smooth hard surface. Each pass is different to the previous pass. Which of the following is incorrect? (2 answers req'd)

(a) Passes overlap one another by 25%
(b) Passes overlap one another by 50%
(c) Once a series of passes is completed in one direction, the next series of passes is at right angles to the first.
(d) Once a series of passes is completed in one direction, the next series of passes is in the opposite direction to the first

(a&c) To improve the flatness, laps are 25%. To improve surface levelness ,alternate passes are at right angles to one another.

At the completion of their session, the students can receive their final score. Not all questions need be completed in any of the categories, nor in any one sitting. The student's final score is recorded on the coordinators "student exercise marks" page for portion of the student's overall assessment in the subject.

Construction Image Questions

In addition to the tutorial questions, there is a bank of questions / exercises related to the digital construction images for the students to review and answer. The purpose of this section is to ensure that all the students review the lecture images shown during lectures, thus reinforcing the contextual relationship between theory and practice, and to provide the visual links so essential in the understanding of construction technology.

Having completed the practice construction image questions, the students can then proceed to the "On-line Test" of images from the construction image database. Students are asked questions on individual images or a series of images. Clicking on the "View Images" icon generates a vertical row of thumbnail images on the screen. Each image has its own number. Double clicking on any thumbnail produces a full screen image.
The typical set of questions below, relate to a series of thumbnail images (also listed below).

Review the images 144 – 150 (QP2 warehouse facility at Broadmeadows)

1. What is the method of construction?
   - (a) Long strip method
   - (b) Double strip pour method
   - (c) Wide / large area pour method
   - *(b) Rail shown on images 144 / 149*

2. Which image best depicts a uniform head of concrete at the vibrating screed?
   145

3. Which image best indicates that the vibrating screed is supported on an intermediate rail?
   148

4. On image 146 & 150, what do the 2 bottles on the ride on helicopter contain?
   - (a) water
   - (b) Set accelerator
   - (c) Set retarder
   - *(c) Retarder used to slow date rate of set if concrete is harder on the surface in some areas compared with other areas*

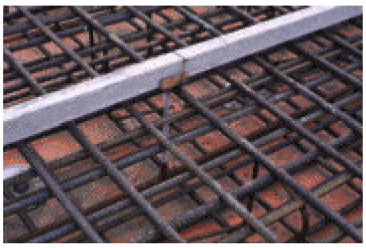
	ID
	0144
	0145
	0146
	0147
	0148
	0149
	0150

Figure 1. Example digital image set

Immediate feedback is provided with a response as to whether the answer is correct or not, followed by an explanation for the correct answer. On completion of the on-line test, the total score is shown and the tally recorded on the coordinator's spreadsheet. The role of the marking is firstly to provide the student with a self-assessment score and secondly to give some indication through the spreadsheet, of areas where the students have not grasped the concepts; enabling the lecturer to review and cover these issues in other tutorial sessions. They marking also provides some degree of assurance that the students will actually complete the exercises as they form part of the overall assessment.

Delivery Strategy & Coordinator's Index Page

The VDMCS coordinator's page provides and allows the lecturer to:

- View the students' Exercise marks
- Update the question set
- Turn access to the web based package "off" or "on"

View the student's exercise marks

Each students progress can be ascertained and checked with their scores monitored for each topic, including the image questions. Poor aggregate scores within one topic are easily identified and further explanation if required can be given to the students in the tutorial sessions. This provides useful immediate feedback to the lecturer on student progress.

Update the question set

All the multiple choice and digital image questions are set up on a matrix grid which can be altered / updated by the lecturer / coordinator. The questions that are currently online are divided into three categories:

1. Online examples that serve as practice questions for the tests.
2. Questions used for testing.
3. Questions stored in a separate bank for use in future years.

Three sets of questions (set A, set B, set C) can therefore be cycled through the examples-bank-test cycle over a three year period: Refer table 1 below.

	2001/4	2002/5	2003/6
Examples	A	C	B
Bank	B	A	C
Test	C	B	A

Table 1

The following table starts with the non-image questions that are currently online and divides them into those that will remain online as practice examples (set A), those that will be used in a hard-copy test this year (set C), and those that will be stored away for use as test questions next year (set B). The image questions are treated in the same way except the test was administered online.

	Online Examples	Hard-copy Test	Bank
Design Principles	1-4	5-9	10-14
Pouring sequences	1-2	3-5	6-7
Joint types and Details	1-6	7-13	14-20
Formwork and joint detailing	1-2	3-5	6-7

Pouring methods	1-3	4-7	8-10
Trowelling methods	1-3	4-6	7-9
Surface finishes and tolerances	1-3	4-6	7-9
Curing and sealants	1-2	3-5	6-7

	Online Examples	**Online Test**	**Bank**
Image Questions	1-4	5-26	27-34

Table 2

As indicated above, the students have practice questions and test questions to complete. All test questions are automatically recorded and can be viewed by the lecturer. It is very easy for the lecturer to overview the results and check those students who are falling behind or those who have not completed parts or all of the tests. Marking and assessment time is drastically reduced in contrast to conventional tutorial programs.

Assessment Modes and Weighting

A hard copy test of the multiple-choice questions was the preferred test mode as there were insufficient computer terminals within the faculty for all students to complete the test at one time. The test could have been turned on and made available online for students to complete within a specified time period (at the university or at home), but this could easily lead to group sittings and collusion by students. The test carried a weighting of 10% of the total assessment.

The on-line visual test can be turned off or on by the lecturer so that a specific time frame can be given for the students to complete the visual test which carried a weighting of 5% of the total assessment. This hopefully prevents collusion between students in giving answers to one another.

The 25% difference in the average scores between the two test modes, suggests that:

- there was some group sittings and collusion between students
- the visual image test was far easier than the multiple-choice test
- students perform better in a relaxed and less time restrained environment than in the traditional test / exam mode

Construction Image Database

A digital image database with over 3,000 images from past and current construction sites has been developed. This allows the students to view any images shown during lectures (or a multitude of other images not shown during lectures) in their own time. The images have been taken from numerous sites over many years and indicate a variety of construction methods for each topic covered in the lecture programs. These images are proving to be a valuable additional resource as they indicate the key issues of:

- Construction methods and alternatives
- Design methods
- Construction detailing
- Construction sequence

- Ability to compare and contrast different site methods
- Buildability issues
- Equipment
- Site Tolerances

Anecdotal evidence from students suggests that they are realizing the advantages of reviewing images shown in lectures as a revision process and for use in assignments both in this subject and others.

The database searches by keywords (any field) for:

1 Description, Topic, Construction system / method, Image number or sequence, Site address or location, Proprietary name, Building name, Australian Standard Method of Measurement reference and Element code

New images are continually being added whilst data entry for each image continues. The database contains over 350 images related to industrial ground slab construction.

Discussion & Conclusions

If web-based activities form part of a student's assessment and the activity is outside of tutorial session times, collusion between students needs to be addressed or the tutorial percentage reduced accordingly.

The automatic marking of student's answers and spreadsheets of the exercises results, dramatically reduces the lecturer's marking time when compared to the more traditional tutorial or assignment submissions. In addition the spreadsheet can provide useful feedback to the lecturer on individual student progress.

The web package accommodates the self-paced learning styles as discussed by Atkinson and Shriffen (1968), with the students able to work through practice questions and receive immediate feedback, prior to attempting the test questions.

Whilst the construction images cannot replace actual site visits, they do provide overall construction sequencing, detailing and site to site comparisons. In addition to the lecturer's explanations of the images, the database can provide a second look at the links between design theory and construction practice, reinforcing the student's contextual understanding. These are key issues as shown by Ramsden (1988) and Seracino et al (2001). Some further development is required to make reviewing the construction image database a component of the package, perhaps as an extension of the image questions. The construction image database does however cover many other topics within this and other subjects within the overall program, not just the industrial ground slabs component.

The web-based package developed and the construction image database can provide additional and alternative teaching tools encompassing different student learning modes. Construction technology is an intrinsically visual discipline and both the image questions and database have purposely been incorporated into the package to provide visual and contextual links between theory and practice. Self-paced learning and immediate feedback with scores and reasons for correct answers are other features that help enhance the student experience and understanding. To generate interest amongst the students in the highly complex and ever changing field of construction technology, face-to-face contact is essential. The teaching needs enthusiasm and a multi-disciplinary approach as outlined by Walker and Vines (1997) and Menser (2001). The overall effectiveness is dependent upon creating that environment through teacher commitment.

This module of "Industrial Ground Slab Design and Construction", forms one topic only out of a total of 6 for the subject. On completion of the module, the students should be confident in addressing the rationale engineering design concepts, subbase preparation requirements, construction sequences and coordination, pouring methods, joints layouts and detailing, trowelling methods and means of achieving floor tolerance specifications. These are the basic concepts and knowledge base required of site managers. Other topics within this subject aim to provide the students with similar skills.

Future Developments

- Inclusion of digital video clips into the construction image database
- Development of a freestanding CD ROM

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A Multi-Modal Approach to Teaching and Learning: A Case Study of Teaching Materials and Process Engineering

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***Abstract**: How we effectively plan, coordinate, resource and promote change is of ongoing concern to those who work in Higher Education. Increased pressure from diminishing resources, intensified competition and changing obligations towards quality assurance and accountability has placed enormous strain on teaching academics. This paper seeks to examine an initiative where the delivery and assessment of a first year materials engineering subject was integrated with an online Learning Management System know as Blackboard©, to reduced correction time and increased student participation and satisfaction. Examples are given of how the technology available within the learning management system can be used to support laboratory work, whilst still engaging the student and staff in hands-on experimental work. Associated online learning aspects such as timely feedback, online assessment management, collaboration, group work and group communications are discussed in relation to current teaching and learning methodology.*

***Keywords**: collaborative, learning, assessment, multi-modal*

Introduction

During the latter half of 2001 Swinburne University of Technology implemented a policy of online support for all subjects delivered throughout the University. This was achieved through the adoption of a Leaning Management System called Blackboard©. In the early days of Blackboard©, support from the School of Engineering and Science was lackluster. Many academics felt the move online would increase their workload and require them to undertake extensive up-skilling in the technology. A view widely held by many academics throughout Australia (Coaldrake, 2000; Fox, 1999) at the time.

To promote flexible delivery in Engineering and Science, a number of lighthouse projects were identified in an attempt to demonstrate how new technologies could lower academic workload while stimulating learner participation and satisfaction. It was hoped that while going some way to relieving the pressure on academics who were 'time poor" it would also contribute to identifying strategies for enriching the learners experience (Bell, Bush, Nichollson, O'Brien and Tran, 2002). It was decided that a subject where a large cohort of students, who were required to participated in multiple lectures, laboratories and tutorials requiring extensive marking, would be assessed using the online testing facility in Blackboard©. They would also receive online support for the lectures and tutorials. The first year Mechanical Engineering subject "Materials and Processes" (HES1230) was ideal candidate subject for this project as it had 200 students enrolled, required students to undertake a number of lectures, tutorials and laboratories within a tight time schedule and was delivered by academic staff that had demonstrated a prior commitment to technology.

A project team of academics, teaching and learning advisors, and development staff was formed to look at a number of key issues: the technical skills of the staff; students computer literacy; technology limitations of the delivery platform; accessibility; and the educational relationship between the content, teaching methodology, assessment methodology and course outcomes. A project scope was developed, management support was sought and institute resources were allocated. The University was looking for ways in which the use of technology could be mainstreamed across the university, linking it to external clients to optimise convenience and accessible for students (Coaldrake and Steedman, 1999). In addition they suggested that " the impact of technology is felt more widely throughout Higher Education, and as increasing numbers of part-time and mature age students attend university, the boundaries between distance education and on-campus delivery will blur, and the distinctions in staff work underpinning the two modes will become harder to sustain."

From the outset, the project team was committed to establishing some fundamental principles to maintain the integrity of teaching process while ensuring online delivery did not jeopardise the learning experience for participants. This was achieved through the adoption of Swinburne's Flexible Learning and Teaching Development Plan (Table 1 and Table 2) which provides baseline expectations for all online subjects throughout the university. From this baseline, which specifically outlines minimum standards for resources, communications, assessment, evaluation and management (Table 1) it was easy to move to developing enhanced features (Table 2) where more innovative practices in HES 1230 could be trialed and evaluated.

The innovations undertaken by the academics and project team involved, correlated well with educational expectations put forward by Swinburne University in their plan (Table 1 and Table 2) as the enhanced features for HES 1230 were based on the five innovations outlined in Table 1. These innovations correlated with the educational expectations as follows:

> The design and development of educational materials provided comprehensive access to **subject resources** as all print based resources were available online in compressed format and ready to print. Other online resources such as journal articles, online reserve items; URLs, online activities, email, announcements and chats were imbedded into the delivery model.
>
> The curriculum design of the subject involved many examples of **flexible communication**, **timely assessment**, **subject evaluation** and **flexible subject management**, often allowing students the opportunity to select their time, place and pace of study. Built into the materials was a sensitivity to learning styles. Participants were given the opportunity to access and select a variety of online resources and activities, which all addressed the learning outcomes.
>
> Learning activities and interactions were implemented using a **flexible means of communication** for example; email forums and electronic discussion boards were widely

used to facilitate whole group and small group communication; **evaluation**, publication of results, formal assessment and marking of laboratories and tutorials was online and available 24 hours a day, 7 days a week.

Currently all subject and program evaluations at Swinburne are carried electronically through anon online surveys via Blackboard enhancing a flexible approach to **subject and program management**.

Subject Trial and Delivery

Students enrolled in first year engineering at Swinburne University of Technology must undertake the first year subject "Materials and Processes" (HES1230). This subject is taught at the mainland campus in Hawthorn and at the recently established Malaysian campus in Sarawak. Because of staff number minimization, and re-allocation of teaching resources, a novel approach was developed for the teaching of this subject

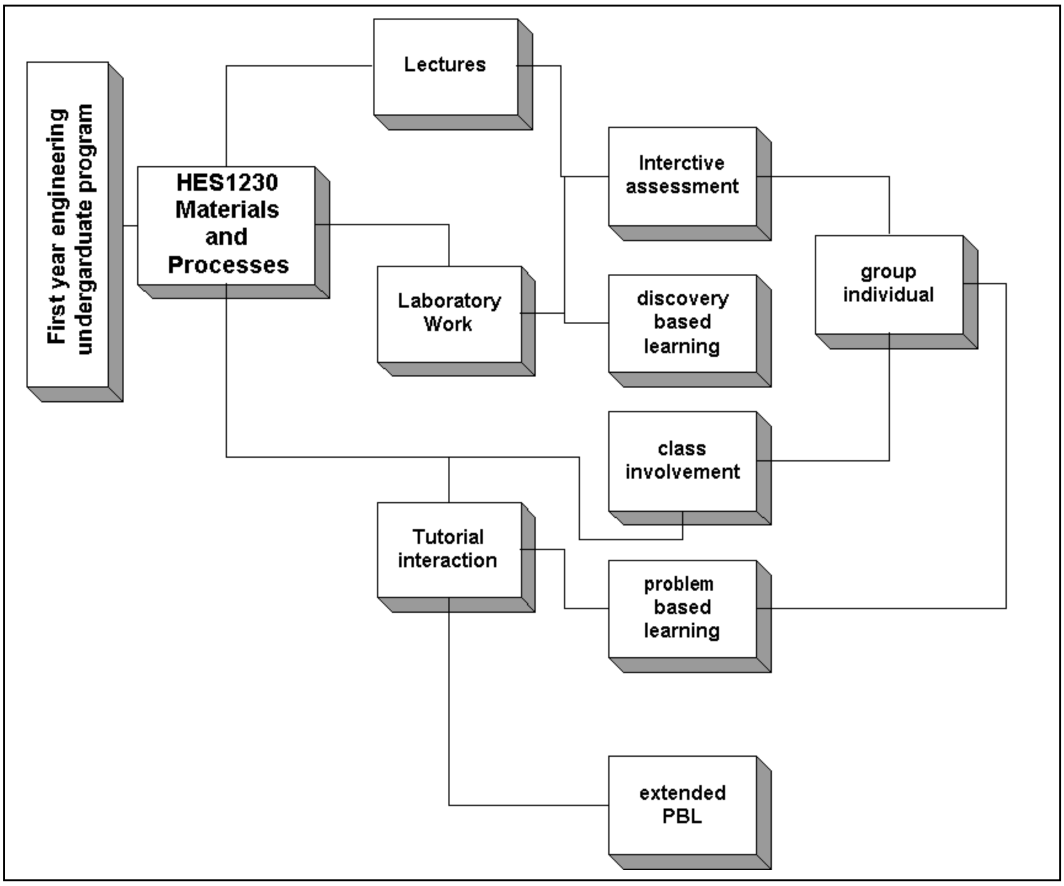

Figure 1: A schematic illustration of the subject delivery and teaching and learning process

It involved the use of new technologies in the delivery of learning material (Foertsch, Moses, Strikwerda. and Litzkow, 2002), the conduct of online tutorials (Tutoring Materials, 2003) and laboratory classes (Ogot, 2003). A schematic illustration of the delivery process is given in Figure 1 and is further explained in the text below.

The main cohort of students numbered approximately 200. The lecture theatre resources only accommodated half that number. In addition, only one lecturer was available for the delivery of lectures. The large number of students and a single lecturer, resulted in a large workload for the delivery of classes, tutorials and laboratories compounded by the need for timely and pedagogically sound assessment for all these activities. To address these issues a new e-learning approach for delivery of material and associated assessment was developed and trialed.

Baseline expectations for flexibility of all current subjects

Educational expectations	Subject sites online
☐ Student access to subject **resources** at time, place, pace of their choosing (e.g. through provision of subject learning guides, lecture notes, readings and references electronically or in print; electronic resource links; Powerpoint slides online; lectures on video-on-demand, streaming video and streamed audio). ☐ Enhancement of student to student and student to lecturer interaction through flexible means of **communications** (e.g. electronic discussion boards, email, electronic chat, video-conferencing). ☐ Provision of timely **assessment** of student progress (e.g. negotiated assessment tasks, using electronic pool/assessment manager, quizzes, online submission of assignments). ☐ Provision for subject **evaluation** using flexible means (e.g. electronic surveys, discussion boards, other informal feedback). ☐ Flexible approaches to subject **management** (e.g. using announcement facilities on subject web pages, electronic bulletin boards, email).	☐ Subject code and title correct ☐ Unused navigation components, communications and electronic tools not visible ☐ Consistency in the structure of presentation of information and activities ☐ Availability online of subject outlines including objectives and assessment requirements ☐ Availability of learning resources such as lecture notes and slides prior to lectures ☐ An online announcement including a welcome and basic information such as attendance requirements and session details ☐ Subject open to allow student access

Table 1: Swinburne's Flexible Learning and Teaching Development Plan, 1 detailing baseline expectations for all online subjects throughout the university.

The Lecture Series

Due to the large enrolment cohort, and staff redeployment, two lecture streams were conducted in parallel, but disjointed in time. However, the students benefited from such a delivery mode, with the enhanced features for learning (and teaching) being shown in Table

2. The delivery of lecture material was coordinated through Blackboard© and audio-visual presentations employing Microsoft PowerPoint©. Student notes were distributed via the Blackboard© environment in pdf (Adobe Acrobat©) format. Students were expected to download the notes before the class, consult appropriate references and come to class ready to engage the lecturer and their peers in appropriate discourse.

Enhanced features for selected subjects	
Innovations undertaken by individual academics and course teams	**Some possibilities supported by LTS**
□ Innovations in the design and development of educational materials □ Innovations in curriculum design □ Innovations in learning activities and interactions □ Innovations in educational communications □ Innovations in assessment □ Innovations in subject and program evaluation	□ Student to student and student to lecturer educational interaction using a variety of flexible electronic communication tools (e.g. threaded discussions, virtual chat, video conferencing, email). □ Adoption of innovative approaches to student centered learning and teaching (e.g. problem based learning, action learning) incorporating graduate attributes and Swinburne themes. □ Provision of evidence of coherence between subject outline and curriculum development. □ Efficient and effective use of technology to improve access to learning and teaching resources for international, on/off campus, fleximode students (e.g. metadata tagging). □ Adoption of a variety of forms of assessment (e.g. formative and summative assessment using quizzes, electronic submission, negotiated learning contracts, group projects). □ Ongoing subject improvement. □ Effective and efficient use of technology to manage student administration (e.g. regular use of announcements/bulletin boards, results via online gradebook, group management).

Table 2: Swinburne's Flexible Learning and Teaching Development Plan for developing enhanced features and innovative practices in HES 1230.

To ensure that lecture materials were reviewed by students, each set of notes had sections missing, which could only be obtained by attending the appropriate class. These were not merely skeleton or fill in the gap notes, but were a substantive set of notes in there own right. Main points were emphasized and analyzed in class and operated as an addendum to the written materials. The pre-identified main points were the central focus or theme for the particular class. Although a whole semester of notes could be downloaded, the main focus of each class could only be obtained by physical attendance at the class. Communication with such a large cohort of students was achieved initially through face–to-face contact, but the amount of time consumed communicating this way severely limited the academics opportunity to undertake other academic pursuits. To try and overcome this issue, an online question and answer forum was established using Blackboard©. For the majority of situations this worked well, as a peer tutoring environment was established amongst students along with the traditional lecturer/student form of tutoring. Students were given the opportunity to undertake group projects in an attempt to improve teamwork skills.

When lecturing to large classes it is sometimes difficult to answer all the questions put forward by students. Often students will approach a lecturer after the class seeking to ask clarifying questions. Unfortunately given this scenario the rest of the class does not have the opportunity to listen to the answers provided. In some cases students can often be reluctant to ask questions in person. For these reasons a Frequently Asked Question (FAQ) "e-mail forum" was set up through Blackboard© giving students the opportunity to ask each other (e.g. peer group learning) as well as staff, various focused questions. This form of WWW e-mail is often not regarded as a medium for electronic learning, despite most undergraduates, and all staff, having access to the technology.

Ongoing Assessment of Lecture Material

With a limited semester of 12 weeks, ongoing assessment using the online Blackboard© system gradebook was initiated. This allowed assessment results to be immediately available through auto correction, as well as providing timely textural feedback to the students. All results were displayed through the online gradebook© in Blackboard©. The assessment procedures and feedback were developed with student needs in mind, and provided students with a current percentage grading of their total semester result. At the commencement of the semester the students were given full details of the timing and topics to be assessed. At the conclusion of each major lecturing theme (approximately 4 and 8 weeks) a class test was conducted online. Students were given one week and one attempt to complete the assessment.

The assessment was quiz based and was composed of a random block of 15 questions from a question pool of 45. Each student was required to logon on to the subject via the Blackboard© system, with a unique username and password. The system was set to allow only one attempt at the assessment item. Prior to undertaking the assessment students had been encouraged to work in groups to promote team-work and research skills. Once logged on each student was presented with a different set (15) of questions. Because of the time constraint, small groups of students worked collaboratively on one student's questions, and when finished, would move on to the next student's unique set of questions which were similar but not necessarily the same. Once a group of four students had completed all 4 question sets then they had intensively discussed each of the problems and had a deeper understanding of the topic. The relatively high score achieved by the students working in this manner evidenced this. Of the students who did not work in a group environment considerably lower scores were recorded although there were of course outliers i.e. those students who worked alone and achieved high scores.

The Laboratory Learning Structure

Laboratory work, an integral part of the subject, was organized so that students participated in experimental work individually. However, the number of laboratory reports were overwhelming for one lecturer to mark and return to students in the time frame allowed. The cohort of approximately 100 students were divided into groups of four students, for each laboratory session, necessitating 25 sessions spread over 4 weeks i.e. approximately 6 laboratory sessions were held in one week. These sessions had to fit into the timetable of the demonstrator as well as laboratory availability. Working in groups of 4, the students would conduct the experiment, take measurements, and record results.

The materials tested were different for the varied groups so that results amongst groups were not always the same. The submission of laboratory results were achieved through a computer based interactive laboratory administered through Blackboard© a program similar to a quiz. Only the students who had participated in the laboratory group could satisfactorily answer all the questions. As part of the laboratory work, the individual participants had to perform calculations, consult their textbook and class notes for appropriate descriptions, and in some instances, use alternate references to understand the concepts requires of them which were associated with the laboratory work. This style of delivery is considered to be a form of Discovery Based Learning (SES Student Manual, 2003; Engineered Materials Website, 2003). Examples of the concepts and applications of this mode of learning are given in Table 3. The laboratory-based exercises varied and comprised several examples where extensive laboratory equipment was utilized. This allowed students to gain exposure to equipment and techniques such as tensile testers, hardness testers, and operation of heat treatment furnaces, whilst participating in more student-centered learning.

Materials are everywhere around you, from the computer mouse under your hand to the wooden computer desk. Materials selected for different uses are chosen because their properties fit the need. But no matter where the material originated, it's properties, processing and performance are all interdependent and interrelated. These material properties, such as strength, can be measured and analysed using tensile testing equipment.

Key concepts:

People have exploited materials for useful purposes.
Find out that the structure, properties, processing, and performances of materials are all interdependent and interrelated.
Learn about the different types of engineered solid materials.
Learn the useful engineering properties of materials.
Hardness is an important property of materials. Learn how to measure and choose the correct hardness test

Learning Objectives:

After completing this module, you will be able to:

- State how structure, properties, processing and performance are all interdependent and interrelated for a given material
- Identify useful properties of a given an engineered solid material (i.e. composite, ceramic, metal, polymer)
- Choose the correct test to measure strength
- Discovery based learning via 'hand-on' experimental.

Table 3: Concepts of Discovery based learning applied to engineering materials

Ongoing Laboratory Work Assessment

The students worked as groups to research the topic but were required to submit individual results, thus promoting peer group tutoring to arrive at appropriate answers. The students were given different sets of conditions to answer as individuals, thus providing another form of learning many aspect of the laboratory work, both theoretical and experimental. In all instances, the submission of experimental outcomes was of a high standard. It appeared that the group work had succeeded in the student's learning process.

The Tutorial System

The most difficult aspect of applying the e-learning process was the implementation of the tutorial. The subject, Materials and Processes, HES1230, was assigned a one-hour tutorial each week as well as a laboratory class every alternate week.

The tutorials were conducted in a face-to-face environment to classes of approximately 24 students. The tutorial sessions were used to explain, in depth, concepts from the lecture sessions that were considered important. However, not all students had the same difficulty with the same sections of the lecture material and needed support in varied and diverse areas of the curriculum.

To overcome this phenomenon various online practice exercises were developed in Blackboard© to enhance student understanding. Problems were set for solution for each tutorial; these problems covered lecture content as well as extension activities. Students reported a high satisfaction rate with the concept and staff reported increased understanding of the topic as well as heightened problem solving skills. The worked solutions to all the problems were available to the students as part of the feedback in the Blackboard© Learning System.

Students were given the opportunity to gain content knowledge through a variety of online and face-to-face mechanisms. Some students took part in class discussions of a particular aspect of their work, others attempted problems in class with tutor support, whilst another group of students enhanced their understanding by discussing problems amongst themselves and working collaboratively to solve them. Adopting this style of delivery allowed for multifaceted learning to take place. The tutors (in many instances the same person as the lecturer) were able to be more efficient in their teaching. This efficiency came, not from employing a totally new online teaching methodology but rather through timely presentation of material, use of peer support and utilization of self paced activities as extension exercises via Blackboard©. New technologies were not necessarily driving the process but rather supporting it.

Concluding Remarks

New Technologies are just another set of tools to be used in the practical implementation of good teaching principles, and as such, must be trialed and evaluated as they become available. Many will enhance the learning process while others will become redundant. What is of importance is the commitment by academics to undertaking reflection and continuous improvement in their teaching practice.

Certainly, time will need to be spent on acquiring new technology skills and expertise within the medium, but the increased diversity of resources, flexibility and timeliness of communication along with the responsiveness of formal assessment are likely to increase student engagement and promote self directed learning. One of the most pleasing aspects of the trial was increased cooperative and collaborative learning amongst students. A skill not easy to enhance in large first year subject deliveries.

It has been demonstrated that successful and effective flexible delivery is underpinned by the same principles as successful and effective face-to-face delivery. The learning-teaching process requires:

- The establishment of clear goals and expectations,
- The alignment of objectives, learning activities and assessment,
- The use of active learning methods,
- The creation of a supportive environments that are inclusive of the diversity of students,
- The enhancement of generic skills and autonomy, and;
- The focus on continuous improvement through evaluation and review.

(McAlpine, Koppi, McLean, Hodgson, Fardouly and Kinch (2001)

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"How can we have ethical and sustainable engineering in a world dominated by market forces?"

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Abstract: *In this paper we reflect on the world dominated by market forces; that globalisation is working for the few, not for the many; that international trade is becoming increasingly knowledge intensive; that globalisation is exploitative and oppressive; and that engineers need to work in this environment. Engineers cannot divorce themselves from this context as their work is intimately enmeshed with the stakeholders of the global marketplace.*

The paper calls for the engineering education curriculum to focus on the ethics of engineering practice as a matter of urgency. We need a shared ethics of engineering practice grounded in an understanding of the rights and responsibilities of engineering in a global context, and commitment to make engineering work for the poor.

Engineering and engineers must learn to perceive social, political, and economic contradictions, and to take action against the oppressive elements of reality by way of participative democratic processes. Working with the polity must become the norm in engineering practice. Engineering education must make this paradigmatic shift in order to become ethical and sustainable in the global context.

Keywords: *globalisation, sustainability, knowledge-intensive, oppression, participative democracy*

Introduction

> *"The **self-organizing principles of markets** that have emerged over the past 10,000 years are in conflict with the **self-organizing principles of ecosystems** that have evolved over the past 3.5 billion years."* Adbusters (2003)

Rapid global developments over the past two decades are impacting on engineering as a philosophy of practice in significant ways. While the practice of engineering has been responsible for many of the technological advances that have contributed to global change, this change has been so dramatic, so rapid and so significant that ethical and sustainable engineering practice is struggling to keep pace.

As engineering educators, we are exhorted to make our curricula global in outlook to keep pace with the changing face of industry, but never to question the ethical implications of these changes and the way they shape our world. A global outlook in engineering education tends to be little more than an understanding that jobs for our graduates are likely to be offshore; that our students need to be able to function in culturally different environments; and that the nature of their work will undergo vast change in their lifetime. There is a lack of attention to and understanding of the impact of globalisation on our societies, on our industries and on the increasingly questionable ethics of the interactions our graduates are likely to have in the global marketplace, particularly in the developing world.

A World Dominated by Market Forces

From an engineering perspective, technological advance strongly correlates with engineering problem solving for societal improvement. Taken in isolation, this is a very worthy objective. However, when coupled with a working environment dominated by market forces, this objective is rapidly subsumed by the all-consuming need to post profits for shareholders. A recent report by OXFAM (2002) on trade, globalisation and poverty argues that globalisation works for the few, not for the many; and that globalisation of trade, which fuels technological advance, currently leads to extremes of prosperity and extremes of poverty. Global markets operate on the basis of fewer and fewer shared values- the ‘bottom line’ has become the dominant one -to the extent that markets now dictate politics and political decision making. Values relating to ethical or sustainable practice or advancement for the social good have all but disappeared in this new climate. Companies of the industrialized world aggressively enter into arrangements that are most profitable for their own interests, but ultimately damaging to the interests of their trade partners in the developing world, creating a kind of 'dictatorship of wealth'. The interdependence of the global economy means that all countries are now more closely linked than ever before and increasingly depend on each other for prosperity, but this dependence does not automatically lead to societal improvements.

The OXFAM report argues that international trade is becoming an increasingly knowledge intensive activity and that trade of high-tech goods in rising fastest of all. Technologies requiring heavy investments in R & D and sophisticated technology infrastructure are now the most dynamic growth areas of international trade. At the same time, advances in computing and telecommunications have brought unprecedented opportunities for the expansion of trade, and the new technologies are creating an ever-denser network of connections between the developed and the developing world. This is one of the defining features of contemporary globalization.

However while new technologies have made globalisation possible, and the transnational corporations make it happen by creating a global marketplace and providing the impetus that drives increased interdependence, the idea that world trade is about countries exchanging goods with each other is an anachronism. Trade, because of the gate-keeping role of the transnational corporations in markets, investment and technology, has become an 'inter-corporate' affair. Access to technology is a requirement for successful entry to the global marketplace, but technology transfer is no longer a simple exchange. In fact it doesn't happen. It is dominated by patents owned by the transnational corporations, and control over technology and the profits that technology offers in a knowledge-based economy are at the heart of disputes about Intellectual Property at the World Trade Organisation (WTO).

Technology is being used to replace labour – in food production (intensive agriculture), in manufacturing (use of machines and robots) and now in knowledge-intense industries (call centers). If selling labour is still the primary engine to make the blood of the market flow – where will this labour be required? It will really only be required in developing nations at exploitative rates of pay and Dickensian working conditions until better ways of production are found.

For very many countries in the developing world, the effects of globalisation have not always been benign. Instead of increasing the knowledge-based wealth of developing countries, technological advances and the control of the global marketplaces by these vast corporations have seen the movement of Research & Development (R&D) out of developing countries. The corporations bring their own R & D into foreign companies, effectively closing down local R & D, which cannot compete either on scale or in terms of investment. In other cases globalisation is producing poverty-level wages, severe forms of exploitation and environmental degradation. Mineral deposits are often located in ecologically fragile areas and on the lands of marginalised groups such as indigenous communities who lack the political power to resist the commercial imperatives of large corporations, resulting, as in the case of copper mining in Indonesia, in severe damage to the environment and an abuse of human rights. Africa contains about one-third of the world's total mineral reserves and is a major producer of oil, gas, diamonds and uranium through the interests of transnational corporations, yet has the most people living in poverty on earth. Malaysian women working in the plating section of electronics factories, servicing the needs of transnational corporations, report health problems ranging from miscarriages to respiratory difficulties. The injuries, risks and long-term damage suffered by unprotected workers represent a labour cost that is not reflected in export prices. (OXFAM, 2002)

The role of engineering in these contexts is also being reduced to a commodity in the market place. Advances in technology made possible by engineering ingenuity, have been hijacked by the rule of markets for the sole purposes of increased profit regardless of ethical and sustainable practice. Take the case of access to water, which is now said to be the new 'oil' of the 21st century. Water is at the heart of life, yet many millions of people around the world do not have access to it, and the current sources and cleanliness are increasingly under threat by unsustainable agricultural practices and global warming. Access to water is becoming the cause of tensions and even war between nations. Many would agree that water should be delivered as a fundamental human right for every person on earth, and that the role of engineers is to develop the technical means of achieving this. However, multinational companies are moving into the water "market" in the developing world, privatising access to this fundamental commodity.

A recent report by the ABC's 'Background Briefing' revealed that 250 million people around the world now pay for water from private companies. When taps are turned on in Adelaide, cash registers ring in London, Paris and Houston. While many would argue that water should not be owned by anyone, the global trends are showing increasing privatisation, and the recent Third World Water Forum in Kyoto highlighted many of the problems associated with this for the developing world. In Kochabamba, Bolivia, the World Bank encouraged a private water company owned by a US transnational corporation to 'solve the problem' of long term water shortages in that area. The result was a 300% increase in the price of water. The people of Kochabamba organised a blockade and 8 days of protest. Martial law was declared and many were injured and killed. This popular pressure eventually forced the government to break the contract with the transnational corporation and return water to collective ownership. The transnational company is now suing the government of Bolivia for $30 million for loss of earnings.

The formal report arising from this World Water Forum run by the World Water Council and multinational corporations aroused massive protest from peoples of the developing world. Private international water companies were strongly represented in the report and the World Bank is closely aligned with the World Water Council, arguing that the only way to tackle the global water issue is to allow private companies to get into poor countries to privatise water. The WWF report ignores the many examples of privatisation that have done nothing but exacerbate the differences between rich and poor. Water privatisation in Manilla resulted in water rates rising by 500% with more rises on the way as the multinational operating the company is operating at a loss and threatens to walk out unless the price of water is raised even more. The cost of this on an average Manillan is 1000 pesos a month for water alone, when they only earn 3000 pesos a month. Globalisation of water is also breaching the rights of indigenous people. Traditional wells are drying up because multinational companies like Coca Cola are extracting massive amounts of water from local aquifers, lowering the water table and reducing access to traditional wells.

While the World Bank needs to be asking who can deliver efficient water services and quality water to the poor at the lowest cost, the current practice is that funding packages from the World Bank are given to the private sector exclusively even though the water issue is not a 'viable' business proposition to companies who can only make profits through improved efficiencies and profits don't come from connecting the world's poorest to the system. SUEZ is the biggest water company in the world with $8 billion turnover a year. At the Kyoto summit, SUEZ was spelling out the problems of trying to make a profit solving the developing world's water problems and put forward strong arguments that the public should carry the risk for the private sector, providing these companies with guarantees against currency fluctuations and other risks. Currency devaluations have impacted adversely on their investments and these multinationals want a 'rebalancing' of these risks between the private and public sectors. They are asking, in effect, for the World Bank to underwrite the risk, providing a subsidy in the order of hundreds of millions of dollars to these private companies, all cloaked in the language of helping the poor. There needs to be more realism about what the private sector can and can't deliver to the world's poor, and our engineers need to be a strong voice in this debate.

There is growing realisation that privatisation is not the answer to world water access and sewage problems, and that multinationals won't be the salvation of the poor. "The truth is that big water projects of the kind the private sector is good at building and operating – with their large reservoirs, pipelines, aqueducts and pumping stations – are largely irrelevant to the needs of the poor. Worse, such projects often end up stealing their water, giving it to cities and commercial farmers." (New Scientist, 1996: 38) There is a clear need for strengthened public utilities and for supporting Non Government Organisations (NGOs) in the developing world to look for solutions for getting clean water to the poor. The same *New Scientist* article reports on the case of the citizens of Orangi, a shantytown in Karachi who "were for decades promised new sewers by the city authorities. Nothing happened so they collected subscriptions and organized a sewer system". This is a case of the public sector supporting local funding to bring sewage systems to large numbers of poor people. They, like Friere (1996), saw that local problems needed to be solved locally and that engineering solutions can be found for local problems. Their schemes have cost 25% of what it would have cost with international money and involvement.

A Call for Ethical Engineering Practice

This is the new environment our graduates will have to work in. No longer will their expertise be confined to their technological knowledge, but they will be required to operate in a fiercely competitive market driven world, developing products and processes that can and are being used to exploit and oppress humanity in the developing world.

The need for ethical engineering practice has never been so urgent. The world has yet to develop institutions and systems of co-operation capable of responding to the problems created by globalisation. Clearly there is a need for a model of inclusive globalisation based on shared values and principles of social justice rather than the immorality of a system ruled by market and commercial values alone. Engineers cannot divorce themselves from this context. Their work is intimately enmeshed with the stakeholders of the global marketplace.

We need a shared ethics of engineering practice grounded in an understanding of the rights and responsibilities of engineering in a global context, and a commitment to make engineering work for the poor. As a group, ethical engineers should take the courage to focus efforts on the critical issues for the 21st Century, not let our effort be frittered away on what the market wants or what may bring us the most money. This effort should be focused on doing *with* the poor not doing *to* the poor.

The Oppression of the Poor

Richard Schaull in the Foreword to Paulo Freire's (1996) revolutionary work reflects on

""the culture of silence" of the dispossessed…. that their ignorance and their lethargy were the direct product of the whole situation of economic, social and political domination – and of paternalism – of which they were victims. Rather than being encouraged and equipped to know and respond to the concrete realities of their world, they were kept "submerged" in a situation in which such critical awareness and response were practically impossible. And it became clear … that the whole education system was one of the major instruments for the maintenance of this culture of silence."

This "submerging" of people in the situation is relevant in two significant ways in this paper – firstly to the oppression of the poor – the humanity in the developing world; and secondly to technologists, and we include engineers in this category. The OXFAM Report provides many examples of the poor and the developing nations being oppressed by the globalisation that is occurring; in general they are not educated to critical awareness.

To change society we need to educate the oppressed so that they can seek freedom for themselves, we need to work with them, not do it for them. The role of the engineer then is partly educator; we need to bring critical awareness to the oppressed. This is a new role for many engineers. Currently a major focus of engineering education is on ways to maximise the business opportunities and to promote understanding of business principles. In an ethical engineering curriculum, engineers also need to learn how to interact with NGOs, focussing on ways to maximise the use of local solutions to local problems.

The Oppression of Technologists

"Our advanced technological society is rapidly making objects of most of us and subtly programming us into conformity to the logic of the system. To the degree that this happens, we are also becoming submerged in a new 'culture of silence'" (Freire, 1996).

In this context the system is the market, and current engineering education and practice, with its almost exclusive emphasis on the development of technical knowledge and skills, even more rapidly makes objects of most of us. Engineering in general, and many engineers, are caught in the trap of conformity to the logic of the system - the modernist engineer sees the world, its institutions as a clockwork machine. **It**, "the thing in question", the objectifying word, is deeply embedded in our language. This is a controlling framework, and this oppression of people fits in with the current hegemony of the market. By controlling the performance of this machine (measuring output and input) and solving problems by using more technology, and by replacing people with technology, engineering practice becomes more and more like horology and less and less action for social improvement and at the same time, the engineering practitioner becomes more and more silent and more and more invisible. The educational practice that leads to this outcome is as much a victim of the oppressive dominance of the hegemony of the market as are the poor in this globalised world.

Beyond Oppression

A change in educational practice is the only way forward. "As the … person learns … , the world becomes radically transformed and he or she is no longer willing to be a mere object responding to uncontrollable change." (Freire, 1996) Engineering educators need to produce technologists who will look beyond the logic of the system, beyond the automatic responses… "the pedagogy of the oppressed must be forged *with*, not *for*, the oppressed in the incessant struggle to regain their humanity…Only as they discover themselves to be "hosts" of the oppressor can they contribute to the midwifery of their liberating pedagogy…The pedagogy of the oppressed is an instrument for their critical discovery that both they and their oppressors are manifestations of dehumanisation." (Friere, 1996) We must begin with the education of engineers and engineering educators. Engineers and engineering need to discover themselves as "hosts" of the oppressor.

We must broaden the education of engineering to encompass not only technology but also the social, political and economic impacts of development. Engineering education must also make a paradigm shift into an eco-systemic understanding so that it becomes adaptive with the environment. It is the critical perception of limit situations as only fetters, rather than as insurmountable barriers, that is required of engineers and engineering to be able to act in ethical and sustainable ways in today's globalised world.

We need to start to think of what we are dealing with as an eco-system not a market. The Market (and modern engineering practice) is monothematic and homogeneous – it is negative, inhuman, and amoral; whereas an eco-system is evolving, human, moral, diverse and heterogeneous.

Goricanec and Young (2003) reflect on the nature of engineering practice when the project and its outcome are considered as an eco-system. This paper proposes a future for engineering where sustainability is deeply embedded in the things that engineering produces (i.e. its outcomes), in the way engineering is practiced (i.e. its operational processes and structures), and in the way engineers and engineering learn (i.e. its evolutionary processes). By examining the concept of sustainable engineering outcomes, in an environment which is fundamentally problematic, and then moving on to examine the necessary prerequisites for sustainable engineering practice, requires us to explicate the necessary adaptations in engineering education and institutional arrangements; the development of active adaptive engineering practice.

Conclusion

Friere (1996) uses the term *conscientizacao* to refer to learning to perceive social, political, and economic contradictions, and to take action against the oppressive elements of reality. We need to teach our students to search for the sorts of contradictions in the world; such as those identified in the first sections of this paper. We also need to see ourselves as politicians – as in William's (2002) quote of Latour's definition of politics: the "progressive composition of a common world".

Williams (2002) argues that.."the sources of creativity necessary to engender change, technological or otherwise, flourish only in a setting with time and space for the intense social interactions that are at the heart of both research and learning." These same intense social interactions (educating to critical consciousness) that are at the heart of both research and learning need to occur when we, as engineers, are "doing it" to other people, other societies. When we are considering doing development for them we should instead be considering how do we engender change with them.

Freire sees education to be the way to freedom from oppression. We need to educate engineers to be reflective of what practice is and what it could be, so that they can see and act as educators of others. For Schon (1983), reflection in action distinguishes the truly outstanding professionals.

Using these ideas - that we are reflective, that we engage people in the creating of solutions for them, locally, that we allow time and space for engagement, that we pursue active adaptive engineering and use an eco-systemic view of development - we can make engineering practice meaningful, sustaining of life, and ultimately create a desirable and feasible future.

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Sustainability and Globalisation: a positive role for engineering

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Abstract: *The paper explores the various meanings and implicit values of the two central concepts, 'sustainability' and 'globalisation', and considers their relevance for twenty-first century engineering education and practice. It discusses social and cultural issues associated with technology development and transfer, including their potential for strengthening communities. The paper concludes by suggesting how the engineering profession can recognise and build on positive values associated with globalisation.*

Keywords: *engineering practice, globalisation, sustainability, values*

Introduction

Discussion of the concepts of *sustainability* and *globalisation* can be unhelpfully woolly and unfocussed. In this paper I will explore some of the competing meanings for these terms and suggest how, as a profession, engineers can respond positively to the forces underlying them. In order to map out sensible future directions for our disciplines, we need to acknowledge the complexities involved and face them squarely. Starting by acknowledging just how value-laden and emotionally charged this topic is may help us to make better sense of it. I make no apology for the fact that this paper is based on strongly held personal values. I will try to make these values explicit, so that they can be examined by my readers and tested against their own values.

Like every other profession, engineering faces a range of challenges in maintaining its relevance, fulfilling its responsibilities, and meeting social expectations for effective performance. The difficulty in meeting these challenges is compounded by both the dynamic nature of engineering practice and the lack of broad understanding of its role and character. Engineering is a social as well as a technical activity. The efforts of the engineering profession have shaped our modern world. Engineering activity underpins our material culture and is central to the production of knowledge and wealth in modern societies. As commerce and industry have taken on an increasingly global character, so have the engineering practices that support them. However, our self-awareness as engineers and our appreciation of the character of our profession have not necessarily kept up with these changes.

The practice of engineering changed rapidly over the twentieth century, and particularly during its last few decades (see, e.g., Johnston *et al*., 2000). Engineers have always managed human and technical resources. In the twenty-first century, engineers are also increasingly required to work across national and cultural boundaries and in multi-disciplinary and even multi-lingual teams. Mathematics, Physics and Chemistry were the scientific disciplines underpinning traditional engineering specialties. As the boundaries of engineering have expanded, Biology and Computer Science have been added, supporting new specialisations.

As part of their work within multi-disciplinary teams, engineers are required to solve technical problems in their own specific disciplinary areas. In engineering, these areas continue to be based on reductionist engineering science approaches, which rigorously eliminate contextual issues from the process of analysis. Preparation for working within these specialised disciplinary areas continues to characterise engineering education, while consideration of the context in which the specialty will be exercised is commonly dismissed as involving 'soft' areas of study, unworthy of attention from 'real' engineering scholars. This narrowly focussed engineering education is inadequate and misleading. Engineering practice involves negotiation across disciplines and coping with the ambiguity and uncertainty that characterise real world technical decision making (Bucciarelli, 1994: 109-110; Vanderberg, 2000). Both the practice and the impacts of the engineering profession are now so powerful and so clearly international in scope that much more serious attention needs to be paid to the sustainability of our work at the global as well as the local level. Indeed, sustainability needs to become a major driver for change in engineering education and practice.

Sustainability

Both *sustainability* and *sustainable development* are contested terms, with a range of approaches and definitions (see, e.g., Beder 1996; Johnston, 1997). Perhaps the most useful way of thinking about *sustainability* is as an ideal state of long-term social, economic and ecological stability, a target towards which we strive, rather than one we expect to reach. The processes of striving towards sustainability, while still pursuing production goals and overall economic growth are commonly referred to as *sustainable development*.

Discussion of *sustainability* and *sustainable development* highlights questions about the extent to which it is possible and acceptable to draw down on the physical resources of the Earth. Since the pioneering work of the Club of Rome (Meadows, 1972) we have developed a more sophisticated understanding of the likely character of global limits to growth (see, e.g., Diesendorf and Hamilton, 1997). In one form or another, such limits exist, and they will constrain the range of our possible futures.

Biocentric or Anthropocentric?

The basic divide in the debate on sustainability and sustainable development is between approaches which can be characterised as anthropocentric (human-centred) and biocentric (concerned for all living things). The latter treats human life as part of the whole system of life on Earth. Its focus is on maintaining the integrity of all of nature's processes, cycles and rhythms. On the other hand, those following human-centred approaches emphasise human standards of living and are more willing to trade off the interests of other species. The Australian Government takes an anthropocentric approach, while environmental organisations like the Australian Conservation Foundation have adopted a more biocentric one (Beder, 1996). In practice, differences focus on environmental issues, and particularly on the extent to which biodiversity needs to be maintained, or to which 'natural capital' can reasonably be replaced by other forms of capital. The assumption that an 'appropriate value' can be put on loss of species or destruction of soils seems desperately shortsighted, particularly in a country like Australia, where half our topsoil has been lost since white settlement. However, this value underpins much of what is still widely described as 'development'. Framing the difference in conceptual and design terms, we might see anthropocentric approaches as corresponding broadly with attempts to dominate nature, while biocentric approaches emphasise working with natural systems and respecting their possibilities and limitations.

The Australian Government policy development process in 1990 and 1991 referred to *ecologically sustainable development* (ESD). The *sustainable development* part of that phrase is particularly problematic, in that 'development' has been widely used to mean increasing resource consumption, while 'ecological sustainability' carried an implication of limiting resource use. While the Brundtland Report (WCED, 1990: 85) defined sustainable development as: 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs', Beder (1995) pointed out that this definition is inadequate for the solution of modern environmental problems.

Issues of values and ethics are embedded in the everyday decisions of engineering practice. When we think deeply about the larger purposes of engineering, what we hope to achieve and how we can best go about our work, it becomes clear that these are matters that we need to discuss seriously and rationally, both within the engineering profession and with other stakeholders, including our clients and the wider community. In this process, sustainability needs to be recognised and accepted as a central value, and one not limited to environmental engineering, as seems commonly the case at present, but consciously incorporated into every specialisation across the whole profession of engineering.

A personal definition of sustainability

Sustainability has strong social, ethical, economic and environmental dimensions. I have tried to come up with a definition of sustainability that I would consider satisfactory, and I have been surprised at how difficult that is. This reflects the disjunction between what I want to happen, and what I see happening around me. I am reluctant to propose an unrealistically utopian definition. However, I am comfortable with nominating key values and directions that decision making with a sustainability focus should aim for. They include:

- Respecting and maintaining the social and cultural quality of life, including life at work;
- Promoting equity of opportunity across and between generations;
- Open, transparent, responsible and consultative decision making processes;
- Recognising the difference between capital and income and only taking what can be replaced;
- Respecting and maintaining the quality and diversity of our natural and built environments;
- Respecting nature and working with it rather than seeking to dominate it.

Positive approaches to sustainability

Engineers can contribute to advancing these values through socially responsible and socially responsive practice. One example would be to move from *technocentric* to *high-performance* design, moving away from using technology to eliminate jobs and towards using technology to maximise the effectiveness of human skill and knowledge in adding variety (and value) to the work they do (Johnston *et al*., 1999: 372-378).

If the world as a whole is to move towards more equitable resource use, affluent groups and nations will need to reduce their rate of resource consumption. Energy consumption on a per capita basis in Australia and Western Europe is about half the US rate, but twenty times that of Asia, excluding Japan (Johnston *et al*., 1999: 444). While people may be prepared to change their focus from standard of living (rate of consumption) to quality of life (satisfaction of human needs), they are only likely to do so willingly if they believe that they are in well-informed control of their choices, in an open and responsive process. One role for engineering expertise in this context is to help consumers to think about the end results they need, for example in terms of *energy services*, like hot showers, or cold drinks. Moving from a *supply* to a *need* focus can help us to optimise energy and other systems in more sustainable ways.

Sustainability presents both technical and ethical challenges for professional engineers. There are potential drivers for change from inside the profession, including increasing attention to systems engineering, and to systems approaches generally (Johnston *et al*., 1999: 64-74). One of the problems with present approaches is the ways the system boundaries are drawn. If we think for example of the transport system, and the way motorcars fit into it, we can see high levels of sub-optimisation. More explicit consideration of systems issues can also broaden the 'discourses' of engineering – the range of issues we accept as proper and relevant when we think and talk and write about engineering. Once we start to consider urban transport systems, we can recognise that vehicle speed and performance are generally more constrained by the context than by the capabilities of the vehicle. We can then come to a more realistic assessment of appropriate and ecologically sustainable technical specifications for individual vehicles. Drawing on structured thinking about preferred futures, and specific techniques like Life Cycle Analysis, we can lift the quality of our decision making to a higher level (Johnston, 2002).

From outside engineering, 'triple bottom line' approaches to corporate accountability (with economic, social and environmental balance sheets: Elkington, 1997) and 'ethical investment funds' (AEI, 2001; EIT, 2001) can give important support for more sustainable approaches to engineering practice. So can regular broad assessment of corporate performance, like the 'Good Reputation Index', promoted by the *Age* and *Sydney Morning Herald* newspapers, which uses community and industry organisations to evaluate corporate performance in terms of: employee management; environmental performance; social impact; ethical performance; financial performance; and market position (SMH, 2001).

As engineers become aware of the importance of futures and sustainability problems, and as circumstances emerge that allow them to initiate positive changes, I believe that attitudes in the profession will respond to the strong leadership given by the Australian professional body (IEAust, 1992, 1997). The Institution of Engineers Australia's annual Engineering Excellence Awards explicitly require consideration of sustainability. I believe that there should also be more specific sustainability awards.

Globalisation

In the development, transfer, adaptation and adoption of technology, the term *globalisation* (or *globalization*, to use the U.S. spelling) highlights the importance of *place* and related cultural issues. We focus on a range of very different issues when we look at globalisation from commercial, engineering, social, cultural or environmental perspectives (see, e.g., Johnston, 2001).

Environmental issues and neo-liberalism

From the late 1960s, people started to see the Earth as a single entity (even as a 'village') and to recognise the extent of global as well as local environmental challenges. Environmental groups proliferated. In a scholarly and well-documented analysis, Beder (1997) shows how transnational corporations fought back at what they saw as environmentalist threats to their power and profit. In the process they established a multi-billion dollar propaganda machine to change the way politicians and the public thought about the environment. Right-wing think tanks were an important part of this strategy, and they have had a significant effect on a range of policy debates, not only on the environment but also on how the idea of globalisation is understood. Their efforts underpin the extreme free market position in the globalisation debate, promoting a neo-liberal (or 'economic rationalist') 'ideology of globalisation' which presents globalisation as a 'natural force' (see also Johnston, 2001). This position has been described by one commentator as a 'crude rationalisation of strictly capitalist interests', which reduces 'societies to economies, economies to markets, and markets to financial flows' (Castells, 1998: 345).

There has been a backlash against this position, and against the extreme volatility of economic prospects associated with this approach to globalisation. Despite pressures for opening up of global trade, regional groupings and nation states still effectively limit access to significant sections of their economies (Castells, 1996: 97-99; Harvey, 2000: 68).

It is obviously futile to try to ignore the fact of global change. However, it is simply a form of economic determinism to deal with the globalisation of commercial activity as if it were an inevitable process, which cannot be challenged. When we consider this issue in terms of sustainability, we can see that accepting such an approach to globalisation has the potential to cause terrible social, economic and environmental damage. I have argued elsewhere (Johnston, 2001) that we need to understand what is happening and work towards directing change into the most appropriate channels.

Globalisation has also been described as a new economic and cultural imperialism, exemplified by US control of the distribution networks for technology and products. We can see the force of this description when we look at the extent to which the US government has been prepared to intervene internationally on behalf of US businesses.

Key Drivers of Globalisation

Harvey (2000: 60-63), a geographer and a recognised authority on globalisation, offers a valuable critical perspective. He characterises globalisation as a profound geographical reorganisation of capitalism. Harvey highlights the extent to which globalisation embodies uneven development around the world. Since 1945 globalisation as a process has been led by the USA and centred on US interests, but he argues that there has been abundant support from a wide variety of other sources. Japan in particular did well in global competition. However, some areas of the globe, including much of Africa, have been increasingly marginalised.

Harvey sees the globalisation process as driven by the interaction of four key elements:

- *financial deregulation*, which began in the USA in the 1970s and has become associated with the promotion of the virtues of 'globalisation'. The establishment of regional power blocs is seen partly as a reaction to uncontrolled deregulation;
- *waves of profound technological change and product innovation and improvement* since the mid 1960s. Increasingly competent technical elites around the world have supported rapid diffusion of these technologies [see also Johnston *et al*., 1999: 409-420];

- *explosive expansion of information and communications technologies* (ICT). With its origins in the military, and conceptualised as an 'information revolution', ICT has allowed financial institutions and multinational capital [and global crime syndicates, (Castells, 1998: 169-211)] to coordinate their activities instantaneously around the globe;
- *rapid reductions in the cost and time of moving commodities and people around the world*, which have facilitated technology transfer and the redistribution of production.

One of our ongoing concerns must be that, in the process of globalisation of technology, there is serious potential for corruption. At the height of the Cold War, data from Transparency International (TI) indicated that bribes had reached as much as twenty or twenty-five percent of international project costs. Large projects involving sophisticated technologies were prime targets for corruption. Even when projects were well matched to the needs of the countries involved, the inflated costs meant that intended economic and social benefits went unrealised. Reports this year on how projects for the reconstruction of Iraq are being allocated cause renewed concern (Johnston *et al*., 1999: 364-365, 420; TI, 2003).

Positive approaches to globalisation

How might globalisation be interpreted in a much more positive way? Cultural issues will certainly be important. An example from my own experience: Finland is the home of the mobile telephone, and young Finns make extensive use of text messaging, with its specific syntax and abbreviations. They also use English extensively in their studies and daily life. Together, these cultural influences cause increasing concern in Finnish society about the extent to which traditional Finnish language skills and Finnish culture are being undermined. Such anecdotal evidence could be replicated in very many parts of the world. I have a mixed response. While I value diversity, I believe that we need to develop a shared global sensitivity as part of moves towards sustainability, and I see improved global communication, possibly based on an 'international' version of English, as having the potential to facilitate it.

Historical evidence shows the importance of cultural sensitivity and of recognising that technologies are neither culturally nor politically neutral. Where technologies are adapted to local conditions and cultural values before they are adopted, they can strengthen local communities and enhance the local quality of life. Scale is an issue here, as is the need to ensure the ongoing availability of necessary technical support. The political, economic and ethical contexts in which international technology development and transfer take place also have an important effect on their social and cultural impacts. Powerful technologies like electrification are typically neither wholly good nor bad, but (as with technology generally) are inherently ambiguous, with overall impacts that depend very much on their detailed implementation. Key factors are how the technology transfer takes place, and who controls the process. Where the community controls and implements the transfer, with a focus on self-reliance and sustainability, the social fabric can be strengthened. However, where change is imposed from outside, the uncontrolled introduction of new technologies can sweep away traditional values and culture and accelerate the destruction of the community (Johnston *et al*., 1999: 389-394).

There is a fundamental conflict here between, on the one side, the individualism that is fundamental to neo-liberalism and underpins an emphasis on personal accumulation and consumption and, on the other side, community-focussed cultural and spiritual values that appear to be central to indigenous cultures around the world. One positive approach to Globalisation would be to see it as 'a fundamental reconceptualization of the universal right for everyone to be treated with dignity and respect as a fully endowed member of our species'

(Harvey, 2000: 94). Movements for a global living wage, and actions by the Zapatistas in Mexico and others to harness global communications links in their struggle for human rights (including maintenance of cultural diversity) suggest that there are real, if vigorously contested, possibilities in this direction. In Australia, I see moves towards Reconciliation and demands for a Treaty with the original Australians as a fundamental starting point from which to move towards the attitudes to justice and equity that must underpin social and cultural (and ultimately economic and ecological) sustainability (see, e.g., Reconciliation Australia 2003).

The increasing complexity of engineering tasks has been one significant effect of globalisation on engineering practice. Some of this complexity results from the need to take account of a wider variety of stakeholders and of linguistic and cultural contexts. Group and team working and learning are even more significant in the knowledge-based organisations in which engineers and others are increasingly working.

Conclusions

Globalisation of the world economy has led to the globalisation of engineering activity. In this paper I have briefly explored and analysed processes of globalisation from an engineering perspective. I have also described some of their implications for changes in the skill and knowledge demands on engineers.

We can see how far we still are from tackling global sustainability problems in a positive and effective way when we recognise Australian and U.S. reluctance to take even such preliminary steps forward as signing the Kyoto Protocol. While we have made some progress, we have a long way to go before engineering educators, the engineering profession, and society generally start seriously to address the problems facing Australia and the world.

For sustainability to be a real prospect, global engineering needs to be more culturally inclusive, and the term globalisation must be reclaimed for the celebration of rich diversity, rather than as a prescription for narrow domination by one or perhaps two regional perspectives. The education and professional formation of engineers needs to develop in them a sympathetic awareness and understanding of the variety of cultures, languages, belief systems, levels of affluence, education and technological competence, in the wider world in which they will increasingly work. In the last few years the engineering profession in Australia and around the world has taken a stronger role in the discussion of infrastructure problems and sustainability generally. With a broadly based professional formation, including a heightened awareness of social responsibility, engineers can play an essential role in the formation of public policy that takes more account of sustainability.

Creating the sorts of preferred global and local futures through which we would wish to live, and which we would want to leave to our grandchildren, will require a strong and positive contribution towards sustainability from the engineering profession. An important prerequisite for this will be for the engineering profession to understand the challenges of globalisation and to incorporate sustainability more effectively into its practice.

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Acknowledgements

This paper is based on the sections on *Globalisation* and *Sustainability and Futures* in my PhD thesis (Johnston, 2002). I thank my colleagues at UTS, and particularly my thesis supervisors, Dr Helen McGregor and Dr Shirley Saunders, for their sustained support and encouragement.

Bringing the Outside, Inside - Engineering for Sustainable Futures

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Abstract: *This paper offers a new paradigm for engineering education and therefore for engineering. This paper proposes a future for engineering where sustainability is deeply embedded in the things that engineering produces (i.e. its outcomes), in the way engineering is practiced (i.e. its operational processes and structures), and in the way engineers and engineering learn (i.e. its evolutionary processes). Further, this paper proceeds on the assumption that the core elements of the engineers' role in modern society are project management, problem solving and solution development.*

We will begin by examining the concept of sustainable engineering outcomes, in an environment which is fundamentally problematic, and then move on to examine the necessary prerequisites for sustainable engineering practice, which, in turn, will require us to explicate the necessary adaptations in engineering education and institutional arrangements.

Keywords*: Sustainability of Engineering Education; Sustainability of Engineering Outcomes; Sustainability of Engineering Practices*

Introduction

To commence, a quote from Rosalind Williams (2002), reflecting on September 11th, 2001

> *"The other thing that is left when the material part of technology collapses is humanity. We always knew that technological systems are composed of both material and social elements, but, as the saying goes, now we get it. That is why the technological catastrophe was also a human catastrophe. People died because all the interlocking systems – aviation, military, safety, health, information – were crawling with humanity: passengers on airplanes, emergency workers in streets, knowledge workers at desks, medics in ambulances, security checkers in airports, mail sorters, postal carriers. They were men and women of all colors, nationalities, languages, and levels of education, only a few of whom could be called engineers. All of them had their lives bound up with the creation, the maintenance, and the use of technological systems……In short, disaster revealed the core truth of*

> *technology and science studies: that technoscience is embedded in human history and human society."*

The quote focuses on the "embededness" of technological artifacts, and this is the key theme of the paper that follows. When one talks about "sustainability" of engineering and its products, we are really talking about the sustainability of the people systems within which a given product of engineering is deeply nested, and whose ends it serves.

This paper proposes a future for engineering where sustainability is deeply embedded in the things that engineering produces (i.e. its outcomes), in the way engineering is practiced (i.e. its operational processes and structures), and in the way engineers and engineering learn (i.e. its evolutionary processes). Further, this paper proceeds on the assumption that the core elements of the engineers' role in modern society are project management, problem solving and solution development.

We will begin by examining the concept of sustainable engineering outcomes, in an environment which is fundamentally problematic, and then move on to examine the necessary prerequisites for sustainable engineering practice, which, in turn, will require us to explicate the necessary evolutionary adaptations in engineering education and institutional arrangements.

Sustainable Engineering Outcomes in a Dynamic Environment

William Wulff, the President of the U.S. National Academy of Engineering, in his paper "The Urgency of Engineering Education Reform" (1998) makes the following point:

> *"Engineering is synthetic - it strives to create what can be. My favorite operational definition of engineering is "design under constraint." Engineering is creating, designing what can be, but it is constrained by nature, by cost, by concerns of safety, reliability, environmental impact, manufacturability, maintainability, and many other such "ilities." Engineering is not "applied science." To be sure, our understanding of nature is one of the constraints we work under, but it is far from the only one, it is seldom the hardest one, and almost never the limiting one.....the practice of engineering is changing. Indeed, those changes are what underlie the urgency I feel for a new approach to engineering education. Growing global competition and the subsequent restructuring of industry, the shift from defense to civilian work, the use of new materials and biological processes, and the explosion of information technology - both as part of the process of engineering and as part of its product - have dramatically and irreversibly changed how engineers work. If anything, the pace of this change is accelerating."*

In this paper we too argue that engineered outcomes and the projects that produce them must, of necessity, be informed by the characteristics of their context. However, we would extend Wulff's argument to put the stress very firmly on the dynamic characteristics of the context – in other words, on the way in which the context, and its constituent components, are changing. By doing this, we are changing the nature of the task, from "fitting in" to "adaptation with".

Traditionally, when learning how to construct buildings, students learn that what lies beneath the building (i.e. the context for the foundations) is integral to successful construction. When learning how to design or choose a computer system, students learn that the design, or choice, has to include consideration of the connections the system has across the whole organisation, and with our global communications infrastructure. Environmental engineering ensures that students, at least, confront the physical and energy links that artifacts are embedded within, and the so-called "unintended" outcomes (e.g. pollution, waste, resource depletion) of all engineering activities. These incremental expansions in the definition of what constitutes engineering have, to all intents and purposes, achieved the status of "common practice".

If one were to trace the trajectory of modern engineering practice, it is possible to discern a gradual move outward, from the object being engineered, to the environment within which it is nested. However, this movement has been piecemeal, driven by specific relationships with specific sub-parts of the overall environment (e.g. the foundations, the waste disposal system, the global "web"). This paper argues that the dynamic environment needs to be brought into the picture in two ways – first, the dynamics which are focused on the specific project in question, and second, the dynamics which any project would have to adapt with – essentially the dynamics which characterise a turbulent environment.

Fred Emery, the Australian Open Systems thinker and researcher, argues that one needs to understand 4 kinds of relations in order to define and achieve a sustainable future for the system (and its projects) you are interested in, where "L" stands for "Lawful Relationship", "1" stands for a system, and "2" stands for its environment. The diagram below portrays these relationships topologically:

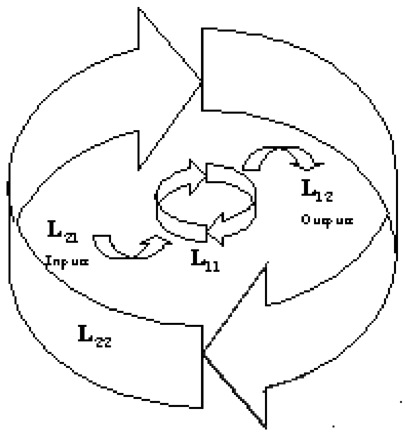

Diagram 1: Topological Representation of System-Environment Relationships

1. L_{11}; relationships within the system/organisation and its projects (eg relationships between project members, structure of steering committees, internal power structure, skill distribution, disciplines involved etc)
2. L_{12}; relationships from the system/organisation and its projects to its environment (what are often labeled as "outputs" - eg prototypes, finished products, new concepts, waste, recommendations for future actions etc).
3. L_{21}; relationships from the environment to the system/organisation and its projects, the conditions that the specific focus of our interest (ie the firm, the project in question) must adapt with (what are often labeled as "inputs" - eg standards, raw materials, available skills, professional expectations/culture, formal project tender specifications, informal client expectations, etc)

4. L_{22}; relationships within the environment, the conditions that **all** systems/organisations, and projects, which share the environment must adapt with. For example,
   - increasing application of technologies to all aspects of life and work,
   - increasing penetration by women into all social economic and political arenas of Western societies,
   - increasing resistance to, and conflict over, the extreme laissez-faire position taken by many governments, and institutions (eg WTO, IMF) globally,
   - increasing homogeneity of global culture and increasing conflict over this trend.

Whereas the core metaphor of traditional engineering is the stable, literally "rock solid" bridges, aqueducts, and buildings of classical civilisation, and the modernist metaphor is the clock-work machine, what we are going to call "*active adaptive engineering*" draws its inspiration from a biological metaphor. The 'project-and-its-tangible product(s)' is but one sub-system of a living, open system, and it is this open system which has to be sustained. The appropriate method for engineering a living, open system is active adaptive planning, using foresight to create a **desirable and feasible** future (or outcomes) for the system as a whole (if this approach had been applied to the Snowy River Scheme, aiming to sustain the Snowy River system, **and** its ability to sustain profitable water resources for agriculture, drinking and power generation over the long-term, the engineered solution would certainly have produced different outcomes to the environmental crisis we've created).

Environmental Types

The most important emergent property of the environment, today, has been the phase change into a "turbulent" (Emery and Trist, 1965) environment. The formal characteristics of turbulence are revealed below, in the classification of environmental types. These types should not be understood as simple graduations on a linear scale, but as qualitatively distinct levels of dynamics and organisation/complexity of the environment, each requiring a different class of adaptive response.

1. **Placid, Random Environment:** Goals and noxients (things to avoid) are unchanging and randomly distributed. In this type of environment, like the economists' "classical market", there is no distinction between tactics and strategy – the optimal strategy is just attempting to do one's best on a purely local basis. Furthermore, the best tactics can be learned by trial and error - the only transactional relations required are L_{11}. Under these (purely theoretical) conditions organisations would exist adaptively as single and rather small units.
2. **Placid, Clustered Environment:** The environment is still relatively static, but goals and noxients exhibit a degree of clustering. It corresponds to the economists' "imperfect competition". Strategy can now be distinguished from tactics – what the organisation knows about its environment becomes crucial for survival - both L_{11} and L_{12} are required for adaptation e.g. a positional strategy, as exhibited in the development of hill-top city states, controlling access, water resources, and arable land immediately below. Further, attempts to achieve an objective may lead into areas of danger, while avoiding a difficult issue may lead away from potentially rewarding areas. This is the class of environment within which human beings first emerged, and within which they have experienced most of their history (around 75-100 thousand years).
3. **Disturbed, Reactive Environment:** In this 3rd type, the environment becomes dynamic. It corresponds to the economists' "oligopoly". It is a level 2 environment within which there are a number of similar, competing, organisations, and this becomes the dominant characteristic of the field. Each organisation has to consider that what it knows can also

be known by the other organisations. Where the organisation wants to move, in the long run, is also where the others will move. Each organisation will wish to improve its own chances by hindering the others, and each will know that the others, not only wish to do likewise, but also know that each knows this.

The organisational response is that of an operation - a planned series of tactical initiatives, calculated reactions by others, and counteractions (ie now, L_{11}, L_{12} and L_{21} are required). It is now more important to define the organisational objective in terms of the ability to make and meet competitive challenges, ie. not focusing so much on location, but on the capacity or power to move, more or less, at will. The causal texture is then determined by the expectations and intentions that guide the moves and counter moves. This is the kind of environment which most organisations today are designed for.

4. **Turbulent Environment:** The dynamics now emerge, not only from the interactions of identifiable component systems, but also from the environment itself. The ‘ground’ is set in motion. Three trends contribute to the emergence of these dynamic field forces:
   - ♦ The growth of organisations, and linked sets of organisations, to meet level 3 conditions; are so large that their actions are both persistent, and strong enough, to induce “autochthonous” processes in the environment. (like the wooden bridge which will, itself, resonate as a consequence of soldiers marching over it in step). For example:
     - Growth of multinational oligopolies in the19th and 20th Centuries, and further development of their global reach during the 21st Century.
     - Growth of large scale competitive organisations (including NGO’s and groups like Trade Unions)
     - Global agricultural “production” and the growth of monocultures, within vertically integrated food companies
     - Intellectual/knowledge “production” and the growth of “heaps of knowledge”
     - All linked through:
       - Oil and other natural resource networks
       - Physical transport networks (land, sea, air, space)
       - Electronic information networks (internet, data, fax, phone, telegraph)
       - Water, gas, electricity networks and the increasing interdependence of these networks with electronic and physical transport networks
   - ♦ The deepening interdependence between economic and social goals - to the point where economic considerations can come to dominate decision making, and some would claim “there is no such thing as society – only the economy” and, concomitantly, that one should strive for continual economic growth at the expense of all other considerations. Economic cycles have a wider impact and a more intensive impact.
     - Outcomes which have no economic value, are assumed to have no value
     - The social consequences of economic behaviour are downgraded
   - ♦ The increasing reliance on research and development to achieve the capacity to meet competitive challenge. This leads to a situation in which a change gradient is continuously present in the environmental field.
     - Amplification of all the other underlying trends; technology increases both the rate of change and the scale of change
     - Technological development increasingly wedded to political, military and economic goals (increases the rate of development, designed for purpose, not cost)

The resulting increased complexity, and the unexpected directionality of these causal interconnections, produces increased **relevant** uncertainty about the requirements for adaptation. Individual organisations, and projects, no matter how powerful, cannot expect to adapt successfully simply through their own direct actions. Now, all four possible relations (L_{11}, L_{12}, L_{21} and L_{22}) must be planned for as a prerequisite for adaptation. What is required in a turbulent environment, over and above tactics, strategy and operations is Active Adaptive Planning, based on an understanding of serial system-environment interactions.

To summarise, in this section we have argued that active adaptive engineering is the appropriate engineering paradigm for the 21st century. We have based our argument on the following facts:
1. Sustaining an engineered solution requires a sustainable ecosystem (system and environment) within which the solution is embedded.
2. The environment has to be understood as more than a collection of things and the relationships between them (i.e. more than its structure) – it also has to be understood as a dynamic whole
3. The current environment is turbulent – introducing a new level of dynamics and complexity into the engineering equation and, concomitantly, a new level of **relevant** uncertainty. This is why the engineering of large projects today is inherently problematic, and unanticipated consequences are the rule rather than the exception.

Sustainable Engineering Practices

Now, engineering practitioners need to learn about the other connections that engineered solutions have – for example with users and other stakeholders, with resources, with public perceptions of utility, with prevailing cultural assumptions etc. The diagram overleaf (Latour, 1999, p110) indicates the 4 main classes of interactions that determine the (potential) sustainability of a (potential) engineered solution are with:
- Logistical activities – what has traditionally been the focus of project management (e.g. the project plan(s) , the business plan, the marketing plan, the IT plan)
- Colleagues - forming coalitions across functional and/or disciplinary boundaries (e.g. with production, marketing or sales functions on the one hand or, with the disciplines that support engineering, on the other) to ensure that the process of designing and developing the (potential) solution is successfully integrated within the organisation, and with respect to, the appropriate reference groups (e.g. professional bodies).
- Potential and existing allies – forming alliances to actually market and sustain the solution (e.g. clients and other stakeholders, like governments, environmental or community groups)
- The public – that is, public perceptions of the functional or aesthetic value of a potential engineered solution.

These processes of planning, designing and researching an engineered solution are highly interdependent, and deeply embedded within a broader set of relationships. For example:
- Linking individual solutions to the complex and interdependent networks of people, resources and technologies which actually co-produce the solution (e.g. attempts to develop alternatives to the traditional automobile have to face the fact that they are not **only** up against “the auto industry”, they are up against an alliance of powerful players in the automotive, liquid fuels, plastics, aluminium, rubber, steel, electronics, advertising, road building, motor vehicle maintenance/spare parts and service industries, as well as

individuated drivers, the driver education industry and governments reliant on roads and petrol related revenues)

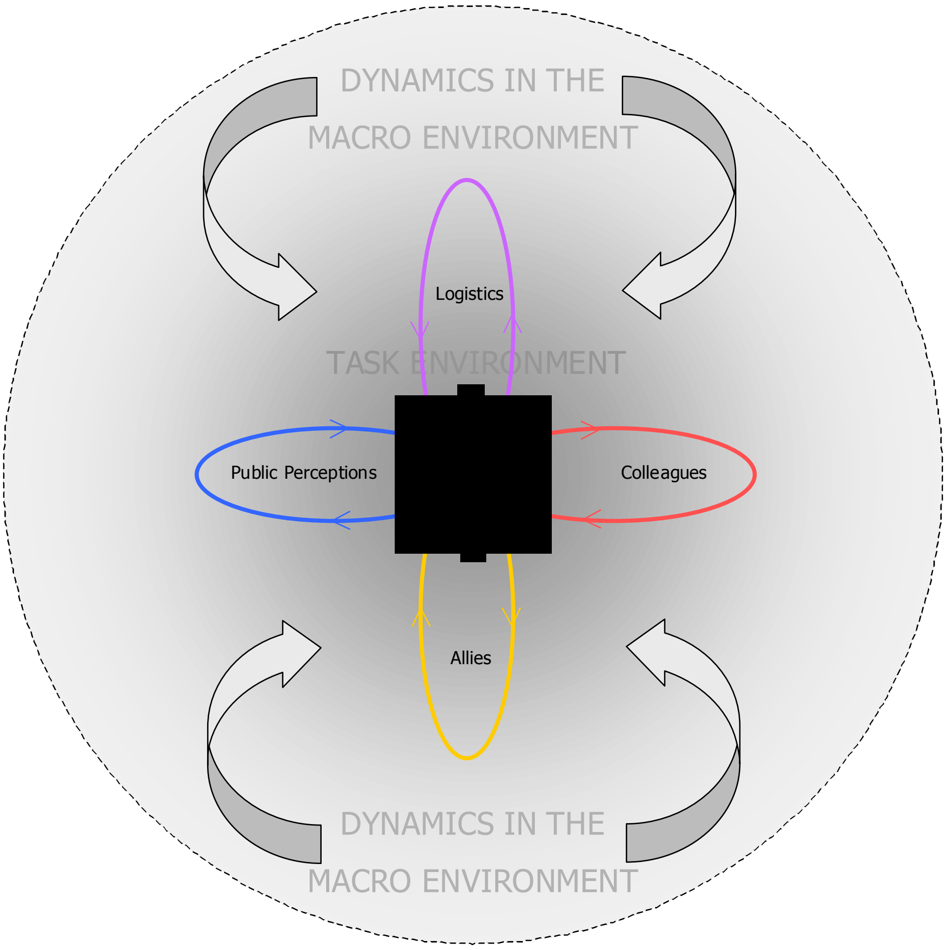

Diagram 2: Sustainable Engineering

- Identifying the right mix of skills, knowledge and tools for a given phase of a project, even for the same kind of artifact. For example, while it can be argued that "a bridge is a bridge, is a bridge", in fact, planning and designing a new bridge over the Burdekin river in far North Queensland, as opposed to the Hindmarsh Island bridge, or the Brisbane foot and bike bridge will require a different mix of skills/knowledge/ tools, because of the relationships these 3 bridges have with the broader social, political, technical and economic task environment they are embedded within. This, essentially, requires a full understanding of the role the solution will play within the whole eco-system it is a part of.
- Discriminating between non-linear projects (ie "wicked" problems, that 'meander' into the world along extended, dynamic and complex networks of people and technologies) and linear projects that can be managed with traditional project management techniques, like the "waterfall" method.(Conklin EJ, 1998)
- Identifying and applying appropriate research techniques to produce reliable answers to the questions arising from the project (eg not only technical research, but also social research, like, which stakeholders will salute, and which ones will give it the "thumbs down" or environmental research, like, an environmental impact assessment of the whole system within which the artifact will play its role).

However, all of these interactions in the so called "task environment", take place within a broader and, increasingly turbulent, macro environment, where, for example, the influence of social, economic and political trends can have a "make-or-break" effect on the responses of potential allies, on access to resources (logistics), on public perceptions, and on the readiness or capacity of colleagues to actively support what they may well see as a "courageous" project.

In a turbulent environment, active adaptive planning is a 3 stage process:

- Institutionalisation of a matrix of systems (Emery 1973, p77) – the building and sustaining of a set of mutually supportive relationships between all the key players in the design, development and delivery of the engineered solution. The relationships between the players need to made robust and predictable if the project, and the engineered solution, are to be sustainable.
- Project strategic planning (Emery 1973, p77) employing the Search Conference (Emery & Emery, 1974) methodology to bring all the key members of the matrix together and define a desirable and feasible future for the project, and the engineered solution
- Project design based on multi-functional project teams (Emery 1973, p77) employing the Participative Design Workshop (Emery & Emery, 1974)

In a turbulent environment these steps have to precede the more detailed project activities summarised in the previous section, or the project, while having a comprehensively adaptive relationship with its immediate task environment, may well be comprehensively maladaptive when it has to proceed within a turbulent environment (some possible examples include; 3G mobile telephony; the Mitcham-Frankston Freeway in Melbourne's south-eastern suburbs; high-rise public housing; the, so called, "dot.com revolution"; most recent IT projects eg RMIT's AMS and many recent intensive tourist developments in Indonesia).

Sustainable Engineering Education (of undergraduates, practising engineers and educators)

The task for engineering education must, increasingly, be the development of a culture of engineering that will enable engineers to deal adaptively with the "progressive composition of a common world" (Latour 2001). The key question then becomes one of organisation – in particular, **how to organise a sustainable technological world** – and by sustainable we must, increasingly, mean a world we can live in. From this perspective the relationships required to develop a sustainable solution can be summarised by "no sustainable innovation without representation"(Latour 2001). In the 3-stage process mentioned in the previous section, the theme that stands-out is the level of participation together with the level of democratic process involved.

To achieve this outcome, engineering and engineering education must become broader, more trans-disciplinary and, at the same time, it must allow itself to dissolve - to give up its assertive, clearly articulated and autonomous professional identity (cut off from the "outsiders" in politics, social inquiry and management).

The following is an outline of the range of subject material which will produce a sustainable engineering practice – through the acquisition of knowledge and skills that link engineering to the ecosystems within which it is practiced. Knowledge is extracted from the context, as appropriate to the task at hand rather than revealed as a series of content "blobs" from which students are expected to make abstractions. Skills in active adaptive engineering are learnt through acting in the context with an appropriate level of understanding of the dynamics of the context.

Some key elements of active adaptive engineering education are

- Focal Engineering, which Moriarty, 2000 defines as adding Knowing Why to the Knowing What and Knowing How of modernist engineering,
- Developing an eco-systemic perspective, that moves beyond the Traditional perspectives of engineering success,
- Pulling the Planning, Research and Design pieces together as an ongoing cycle (Action Research) as in Checkland, 1998,
- Understanding the nature of the "problem", expanding beyond the technical into traditional Socio-Technical and systems thinking,
- Solution development – embedding the solution in the task environment, embedding the solution in the macro environment; ensuring the Innovation is sustainable and using a truly trans-disciplinary approach in Socio-Technical Ensembles (Latour, 1999)
- Understanding the nature of the project to be managed
  - – is the project linear or non-linear?;
  - the extension of Socio-Technical thinking as applied to the Knowledge Industry;
  - "Wicked" problems or saturated interdependency (Conklin)

A Call to use Active Adaptive Engineering to Re-conceptualize Engineering

The world we live in, in the 21st Century, is turbulent. To deal with this environment we must learn to actively adapt with the environment, we need our solutions, to the problems and puzzles which we face, to be sustainable.

This a vastly different paradigm for engineers than the traditional stable, and literally "rock solid" bridges, aqueducts and buildings but also from the modernist metaphor of the "clock-work machine". We need to produce sustainable *outcomes*, to do this we need to practice "active adaptive engineering", and we need engineers and engineering to learn and therefore to evolve.

We need to shift the ground and re-conceptualize engineering and engineering education. To do this, in this turbulent environment, we need to apply the 3 stage process of active adaptive planning:

- Develop an institutionalisation of a matrix of systems. Build and sustain a set of mutually supportive relationships between all the key players in the design, development and delivery of the engineered solution. (a re-conceptualisation of engineering and engineering education). The relationships between the players will need to made robust and predictable if the project, and the engineered solution, are to be sustainable.
- Employ project strategic planning using the Search Conference methodology to bring all the key members of the matrix together and define a desirable and feasible future for the project, and the engineered solution
- design the project based on multi-functional project teams employing the Participative Design Workshop

Following the application of active adaptive planning principles, engineering practice can then move on to apply the comprehensive project management framework outlined in the previous sections. By approaching the engineers' task in this way, one builds sustainability in from the ground up, rather than adding it on to standard practice, like any other baroque variation.

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Presenting a course in renewable energy for engineering students

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Abstract: *The electrical engineering courses at Curtin University were re-structured in 1997 in line with IEAust recommendations to include social, economic and environmental aspects of engineering. The new courses include elective units, one of which, "Renewable Energy Principles", is an example of a unit which combines technical and non-technical aspects of engineering. Subsequently there has been a consolidation process across the university standardising the number of units per semester (to 4) as well as a move to 12 week teaching semesters. Renewable Energy Principles has been revised to fit the new format and remains a popular final year elective unit. The paper gives background information and philosophy on the unit development, details of the unit and feedback from students who have taken the course.*

Keywords: *renewable energy education*

Background

The Department of Electrical and Computer Engineering at Curtin University of Technology has an enrolment of around 450 undergraduate students and offers degree courses in Electrical Power, Communications and Computer Engineering. The School restructured its undergraduate courses in 1997 in line with the review and recommendations for engineering education made by IEAust. This review was appropriately titled "Changing the Culture: Engineering Education into the Future" [1], it proposed cultural changes in the structure of engineering degree courses in Australian universities. Comments from the report such as, "Courses should promote environmental, economic and global awareness and become more attuned to the real concerns of communities", were taken into account when formulating the new electrical engineering courses at Curtin.

Following completion of the common core units in semesters 1-5, students specialise in Electrical, Communications or Computer Engineering in the final three semesters (fig 1). Within these final semesters there is some flexibility via electives. Each of the three departments is expected to provide elective units that are available to all students within the School. There were a number of reasons why the electrical department was keen to offer both an introductory unit and an advanced unit in the field of renewable energy (RE).

Semester 1

Common electrical engineering core units (3) **+ Engineering and society**

Semester 2

Common electrical engineering core units (3.5) **+ Liberal elective**

Semesters 3,4,5

Common electrical engineering core units

Semesters 6,7,8

Specialised electrical engineering units (3/sem) **+Engineering management and 2 elective units**

Figure 1: Outline of current course structure

Engineering courses have been criticised in the past for being narrow with an undue bias towards the purely technical aspects of engineering [2]. The proposed unit in RE would address this problem by exposing students to social and economic issues as well as the engineering aspects of renewable energy systems.

Renewable Energy is one of the major research areas within the electrical engineering department at Curtin (covering photo-voltaic applications, wind energy and remote area power supplies) and many students, especially those from overseas, carry out projects related to these topics at the Centre for Renewable Energy Systems Technology (CRESTA). A unit covering the principles of renewable energy would obviously fit well with this focus and expose undergraduates to some of the interesting developments in the RE field which would lead to enthusiasm for final year projects in RE. Subsequently some of these students may choose to pursue post-graduate research in the field of renewable energy.

A further reason for introducing the new unit has been the popularity of the coursework Masters' program in Renewable Energy (RE). In the past, post-graduates came solely to do research, but increasingly we are attracting PG students who come for one year of coursework. The Master's course in RE is taken mostly by overseas students who are keen to apply RE technology in their home country.

Why are students interested in RE? There is general concern over the production of energy from fossil fuels, this arises from the issue of sustainabity as well as the environmental impact of burning fossil fuels. The Prime Minister has stated that by the year 2010, an additional 2% of Australia's electrical energy will come from renewable sources [3]. Although the implications of this statement are unclear, it has signalled an increased level of support for the production of energy from renewable sources, and led to the establishment of the Austraian Greenhouse Office. In this favourable economic environment several utilities are proceeding with renewable energy projects eg the wind farms at Albany, WA [4] and Woolnorth, Tasmania [5].

In order to rationalise courses across the university a Consolidated Teaching Policy was introduced at Curtin University in 2001, this policy mandated that all courses would consist of 4 units worth 25 credit points, each semester. (One unit can be replaced by 2 'half units'). This year (2003) has seen the introduction of 12 week semesters. In this changing environment it has been "challenging" to include two final year units in the field of renewable energy, Renewable Energy Principles is an introductory unit suitable for all engineering students and Renewable Energy Systems a more advanced unit which looks at the power electronic systems needed to interface with renewable sources of energy. The course structure for REP is shown in the appendix. This is a unit which fits well with the IEAust guidelines and emphasises the need for both technical and social factors to be considered when designing systems based on renewable energy, ie the concept of "appropriate technology".

Course Objectives and Outline

The course objectives for the REP unit were written as a set of enabling skills, which students would acquire by participating in the lecture/lab program.

We placed particular importance on the lab program, which consists of a series of exercises in simulation as well as hands on PV experiments and a field trip.

On successful completion of the course students should be able to:

- describe the fundamental principles of renewable energy systems (wind, solar and hybrid)
- select an optimum system configuration for a given application
- apply best practice design principles to the sizing and operation of renewable energy systems
- be aware of both technical and non-technical issues in the planning stage of renewable energy projects
- perform economic feasibility studies of renewable energy systems
- have an awareness of the potential market of renewable energy technology

All units in the School have a similar structure, two hours lecture combined with two hours laboratory/tutorial per week (ie four hours contact which is worth 25 credit points). The weekly outline of the course is shown in the Appendix. Assessment is normally based on a 2 hour final examination worth 60%, plus assignments 20% and practical work worth 20%. The assessment is linked to the specified course outcomes eg. in the written exam, students are required to size a RE system considering local conditions and constraints. Since the unit is also offered to postgraduates as part of their coursework program, the assignments are modified for these students, but all students take the same written exam.

Running the unit

The current version of the course has been offered since 2002. In 2002 there were 25 students (17 undergrads from electrical engineering and 8 postgraduates), while in 2003 there were 49 students (22 undergrads from electrical engineering, 18 undergrads from other schools and 9 postgraduates). Attracting students from other areas can be a challenge as they bring a different set of pre-conceptions to the course. Exchange students from countries such as Norway, Germany and the US have also taken the course, these students also bring different inputs to the course and demonstrate that renewable energy and sustainable development are topics of global importance.

The course is managed (but not delivered) via WebCT – this facilitates communication with the group - as well as within the group. At the end of each week a summary of the lecture outcomes is posted, along with links to relevant web-sites (especially for wind energy, as the text book [6] only covers solar energy). An advantage of using the electronic bulletin board is that student feedback is much more timely than the usual end of semester surveys. For example some students complained about the conditions in the lecture venue, quickly raised support and this led to a new venue being arranged.

Assignments are also posted on WebCT. I have attempted to give the assignments an individual flavour by specifying a broad problem and then asking students to tailor the problem to a situation of their own choice. Eg one assignment involves the design of a solar home system. Working in pairs, students are able to choose a location of interest (and where they can get weather data) and specify their own load profile.

The reaction of students to the unit has been overwhelmingly positive (as shown by the student unit evaluation) and students seem to take a genuine interest in the topic. There were often points raised in the lectures which led to informative discussions. Eg, a student asked if a voltmeter placed across a PV cell (diode) would measure the barrier potential. My response was to encourage him to take a measurement in the lab and then to refer him to a suitable reference for an explanation.

The presence of the postgraduate students in the group is an added bonus as often these are mature students, sometimes with experience in the renewable energy field, which is helpful, but more importantly they have experience in implementing engineering projects in a variety of environments.

Apart from enjoying the course, most students felt they had gained valuable insights into renewable energy technology and its applications, especially in developing countries. They had a heightened awareness of the social and economic factors associated with introducing a new technology. An example of this topic is grid connected PV systems - why are they popular in Germany but not in Australia?

Conclusion

The paper by Carrie Sonneborn [6] reports that, …"engineers mostly work in controlled environments (large bureaucracies) which restricts their opportunities for making change, (engineers are unlikely to become revolutionaries!) plus engineers are generally less likely to be interested in social issues". Further she goes on to say that …"engineers have an important role to play in creating a sustainable future and in the process the profession could reclaim its positive image". The popularity of the Renewable Energy Principles course is encouraging and augers well for the implementation and acceptance of renewable energy systems in the future. A further aim of the new unit was to demonstrate to students that engineering is more than a narrow technological field of study. To quote from Sharon Beder [2]
"Given the ignorance amongst students and in the community about what engineering is all about, the content of engineering education has provided a window into the profession and

shaped perceptions of it. As a result of the largely mathematical and technical content of the curriculum, engineering is seen as a technical career that combines maths and science rather than one that is involved with people and issues". By introducing the new course, we have attempted to address this bias in the engineering curricula and produce engineering graduates, who, as well as being technically competent, have an awareness of the wider social, economic and environmental issues. A unit such as this, which combines technical, economic and social considerations, is closer to the reality that graduates will be confronted with when they start their careers as professional engineers.

One cannot expect the introduction of one innovative unit, in isolation, to bring about a cultural change in our graduates. However, the unit, Renewable Energy Principles, is presented as an example of the new ethos in the Faculty of Engineering at Curtin University [7]. Examples of other changes in the Faculty which have taken place are:

- the encouragement of women to enrol (and succeed via a support network) in engineering courses.
- the introduction of a Teaching Quality Index in the Faculty to promote good teaching practices etc.
- course feedback sessions where staff meet students to hear their concerns.

The experience of todays engineering students is vastly different from the past and hopefully the university experience equips them with attributes which facilitate their development into professional engineers who are more than just "technically competent".

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Appendix

LECTURE PROGRAM for REP 403/603

Week #	Week starting	2 Hour Lecture Topics	Ref Ch #	Lecture #	Tut #	Lab #	Remarks
1	03-Mar-03	Introduction to renewable energy: Sources and applications; Australia's energy balance; Market potential for renewable energy	1	1	1		Introduction to simulation
2	10-Mar-03	PV energy conversion: Char. of sunlight; the PV effect; PV technologies; PV cell models	2,3	2	2	1	Simulation task 1
3	17-Mar-03	PV cells, modules and arrays: module char; practical aspects of module siting; max power point tracking	4	3	3	2	Simulation task 2
4	24-Mar-03	Introduction to wind energy: Fundamentals of WE generators; wind resource assessment AC Circuits 1	web	4	4	3	Simulation task 2
5	31-Mar-03	Utility scale WE conversion (Utility perspective)	web	5	5	4	Experiment 1 (PV)
6	07-Apr-03	Energy storage in RE systems: Batteries and fuel cells	4,7	6	6	5	Experiment 2 (MPPT) Assignment 1 (out)
7	14-Apr-03	**Tuition Free Week**					
8	21-Apr-03	**Easter Break**					
9	28-Apr-03	Energy services for remote communities: RAPS installations, Solar home systems	4	7	7	6	Simulation task 3 (RAPSIM) Assignment 1 (due)
10	05-May-03	Hybrid energy systems: operation and performance	4	8	8	7	Simulation task 3 (RAPSIM)
11	12-May-03	Hybrid energy systems: performance and design	5	9	9	8	RE Systems 1 (CRESTA)
12	19-May-03	Grid interactive systems: rooftop PV systems; utility scale systems	7	10	10	9	RE Systems 2 (CRESTA) Assignment 2 (out)
13	26-May-03	Economics of RE systems: lifecycle cost analysis; external costs of generation; rebate schemes		11	11	10	RE Systems 3 (CRESTA)
14	02-Jun-03	Future prospects for RE: fossil resources; greenhouse effect; energy efficiency; DSM		12	12		Assignment 2 (in)
15	09-Jun-03	**Study Week**					
16	16-Jun-03	**Examinations**					
17	23-Jun-03	**Examinations**					

- A field trip will be held at a mutually convenient time in week 14.

The Challenges of Educating Engineering and Technology Managers

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Abstract*: The Master of Technology Management (MTM) program aims to produce graduates equipped with essential management knowledge and an appreciation of technologies outside their initial specialisation. The skill set would therefore allow these graduates to manage complex technological or engineering businesses.*
The MTM is being developed by the University of Southern Queensland's Faculty of Engineering and Surveying, and is written by engineers for engineers and other technologists. It is closely linked with the University's MBA program.
Its courses will be offered in part-time, external mode. On-line delivery, and short courses based on the written material, are being considered in the future.
Ensuring that the courses offered in the MTM develop the skills required to manage technology in a dynamic environment has provided a number of challenges to the team developing them. As well as experienced academics, this team includes staff who have come directly from industry, are enthused about the MTM and can contribute significantly to it, but have also had to learn the course development process.
Through this combination of people who have come from industry with experienced academics, the challenges are being addressed so that the Master of Technology Management aims to provide a solid learning experience fort he student, and in doing so to develop highly effective engineering and technology managers.

Keywords*: engineering, technology management, innovation*

Introduction

The Master of Technology Management (MTM) is a postgraduate coursework program being developed by the Faculty of Engineering and Surveying at the University of Southern Queensland (USQ).

It aims to produce graduates that are equipped with essential management knowledge and an appreciation of the latest technologies much broader than their initial specialisation. In doing so, it aims to develop graduates who will manage complex technological or engineering businesses (University of Southern Queensland, 2002, p.7).

The MTM is a six-semester part time program consisting of twelve related courses. Four of these courses are core Master of Business Administration (MBA) courses and eight are specialised technology management courses (University of Southern Queensland, 2002a, pp.7-9). Conversely, an MBA with Technology Management specialisation is offered. It has four core MTM courses plus eight MBA courses

A Master of Professional Engineering, which is oriented to engineers desiring a higher level of engineering specialisation than offered by either the MBA or the MTM, completes the suite of programs (University of Southern Queensland, 2002b).

The MTM will be delivered in part-time external mode. On-line delivery, and short courses based on the written material, are being considered for the future.

Development of the MTM as an effective program for educating engineering and technology managers has provided both challenges and rewards for the development team, which consists of both experienced academics and staff who have joined the University directly from industry.

The Challenges of Technology Management

Definitions

One of the first challenges in developing the MTM courses was to develop meaningful definitions of the terms "technology" and "technology management." A particular challenge was to move beyond the popular view that technology is mainly concerned with information management systems.

The definition adopted for "technology" by the project development team considered both existing definitions and the desired outcome from the MTM, and was "the scientific knowledge base whose outputs are the systems, processes and know-how that are integrated into engineered systems and processes for the betterment of the world."

The definition of "management of technology" was amended from that of the National Research Council, USA (1987). It is as follows:

"Management of technology links engineering, science, and management disciplines to plan, develop, and implement technological capabilities to shape and accomplish the strategic and operational objectives of an organisation and enhance its innovation competency."

Thus, the management of technology encompasses not only the management of existing technology but also the development of organisations so that they are effective and efficient innovators and can implement new technologies.

Development of Managers for a Dynamic Environment

A further challenge has been to develop courses that equip graduates who can effectively and efficiently manage, over the long term, the ever-changing field of technology.

As Tschirky (2001) explains, the discipline of technology management is itself also changing over time. The initial aim of technology management was to close the link between the technological disciplines and general management. The next step was a paradigm shift that brought technology into management, and the third is a new enterprise science view that fully integrates technology-awareness into general management. It is based on the assumption that in research it is possible to draw on all the relevant empirical and science-based areas of scientific knowledge to describe the enterprise.

There are organisations in all three of these stages, and accordingly the MTM – if it is to be successful – will need to address all of them, and also look towards a possible future in which managers of technology will increasingly determine the strategic and operational direction of their organisations.

Description of the MTM

Management courses have been part of undergraduate engineering programs for some time. Ward (1998) chronicles the development of such a course at the University of Technology, Sydney. He notes the importance of aspects such as the human side of management, and the need for management to win.

The MTM endeavours to take the specialised engineering management program into the postgraduate environment. It embraces the above elements, and adds others, in an integrated program that offers:

- Core Master of Business Administration courses (delivered by the University's Faculty of Business) in management and organisational behaviour, economics, accounting and law.
- An integrated suite of specialised technology management courses in technological impact and its management, asset management, risk management and sustainable development.

A choice of four out of six other courses, which logically follow from the four specialised technology management courses.

Complementary Certificate and Graduate Diploma programs are also available.

As well as taking graduate engineering and technology management education beyond that at undergraduate level, the MTM aims to develop the skills needed to compete and be successful in the complex world of technology, engineering and entrepreneurship in which the advanced technological manager will work.

The MTM program was developed out of the recognition that a large number of engineers and other practicing professionals aspire to managerial positions in a technology or engineering environment. It was also recognised that qualified managers of technology play a crucial role in technologically advanced as well as developing societies. Thus it was reasonable to expect that many of these professionals would want to achieve postgraduate qualification in a coursework-based management-focused program (University of Southern Queensland, 2002a, p. 11).

Some of these professionals would be interested in undertaking the MBA with a technology management specialisation. Others would be interested in a more specific technology management oriented master's level business qualification, such as the MTM. There is also an option for students to undertake the Master of Professional Engineering, which allows students to undertake a research project as well as a selected number of MTM and MBA courses.

This structure allows students to select a program that has a mix of closely related business and technology management courses aimed at meeting their particular needs.

This use of a limited number of closely related courses to meet the requirements of three different, yet related programs (Master of Business Administration with technology management specialisation, Master of Technology Management, Master of Professional Engineering) differentiates this set of programs from several of the postgraduate technology management programs offered elsewhere. It allows students to select a program suited to their needs, and know that the courses they are studying are designed to integrate with the other courses in that program. This program structure should therefore be attractive to students interested in a focused postgraduate engineering or technology management program that suits their requirements.

Through being designed as postgraduate programs aimed at ambitious professionals, and accordingly designed to challenge students at a high level, the MTM and its associated programs are distinguished from undergraduate double degrees in engineering and business, which would be expected to appeal to a different group of students.

As there will be an ongoing challenge to maintain and enhance the above features so that they remain relevant to engineering and technology managers into the future, courses in these programs are being designed for maintainability as well as academic rigour.

The MTM and its associated programs are being developed to meet both the requirements expected of coursework postgraduate degrees and the expectations of industry. This presents a further challenge, as the program will be offered in both Australia and overseas, and requirements and expectations may differ across geographical and political regions.

Figure 1 shows the MTM course structure.

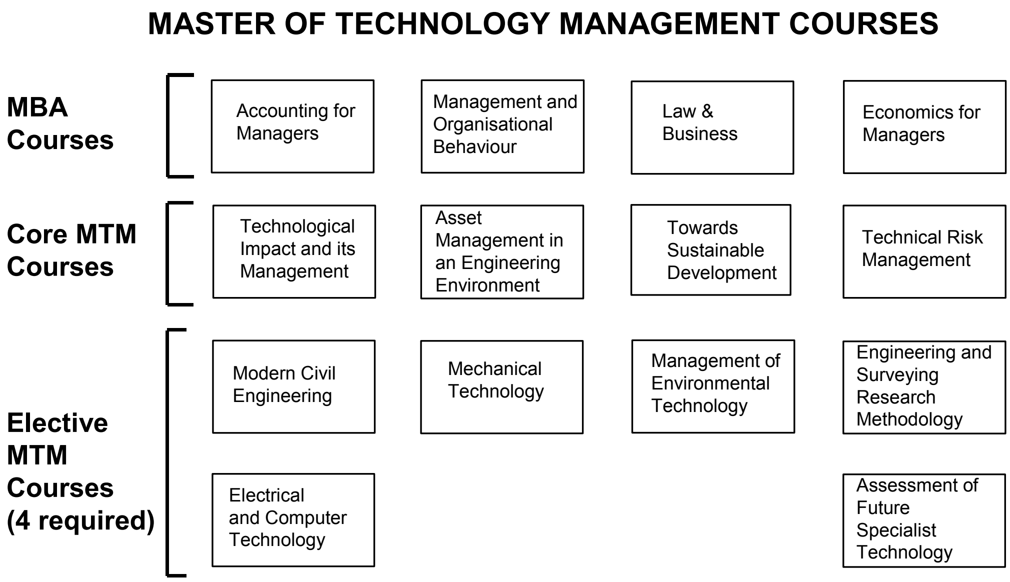

Figure 1 – Master of Technology Management Courses

Delivery of the MTM Courses

Use of Distance Education

One of the factors in developing the MTM was the estimate by the Australian government in 2001 that a total of 240,000 people would take up a loan to undertake postgraduate coursework study over the following five years. Although specific statistics for engineering were not available, there was a clear indication that there was a sizeable market for coursework programs, which could complement the current research programs.

However, the demise of traditional on-campus Masters degrees was evident within Australia and possibly overseas. Therefore, the market demand must be serviced by the non-traditional means of distance education. This tended to be supported by overseas evidence (University of Southern Queensland, 2002a, p. 10).

Therefore, it has been decided to use distance education – a strength of the University of Southern Queensland - to deliver the MTM courses. Teaching and assessment are to be similar to current Faculty of Engineering and Surveying practice.

The combination of strength in distance education with an integrated technology management program that combines the specialist skills of academics in business and engineering skills is expected to develop the MTM into a program that provides students – both in Australia and elsewhere - with a rounded technological management qualification tailored to their needs.

Enhancing the Learning Experience
The MTM courses will be delivered through written documentation, using prepared course material supplemented by texts and readings. Online methods of teaching, which appear to have a number of positive features, will supplement the written materials.

There are numerous studies in the literature on online learning. For example, Macdonald (2001) reported on the use of online interactivity in assignment development and feedback in Britain's Open University, and noted that use of an electronic network allowed for delivery within a controlled time frame whilst providing an interactive environment for debate on alternative perspectives.

In the Australian engineering education environment, Deeks (1999) discussed the use of web-based assignments for structural analysis, and noted that this system was expected to improve the deep learning of the material presented. Another paper by Kirkpatrick and McLaughlan (1999), discussed use of a web based learning environment incorporating computer mediated technologies for student interaction for problem based learning and professional skills development (a similar environment to that expected for the MTM courses). It provided flexible and responsive support for student interaction and communication.

From studies such as these, online learning has both advantages and challenges, but is likely to be quite useful in promoting student interaction and in the formative assessment process. In the MTM, it is therefore expected that both online discussion groups and directed web-based research will be used. A later stage of development could incorporate online feedback of sample answers to research questions.

This approach will assist in overcoming another challenge in developing the MTM courses so that they effectively educate engineering and technology managers - balancing the amount of detail provided in material between basic material needed to meet learning objectives and the more detailed information demanded by the more enquiring students. The strategy adopted in this case is to provide sufficient material in the written course material, prescribed text and prescribed readings to give basic information; then supplement this material with directed and challenging research, reflection and problem solving tasks. Much of this supplementary material will use online resources.

To facilitate this process, student tasks are classified as “essential”, “important”, “background” or “other”. The material studied in essential tasks provides basic knowledge of the course material, and is usually a key principle in the written course notes or text. Important tasks include reading and understanding explanatory course or text material, or undertaking a reading or exercise that aids understanding of the principles being explained. Examples of background tasks may be directed or undirected research that enhances understanding of course material. Other tasks provide additional learning for students who want to understand a particular topic in more depth. They would typically be undirected research using suggested resources.

Material in essential and important tasks is examinable, while material in background and other tasks is not examinable.

The Course Development Process

Challenges in Course Development

The special challenges of equipping managers of technology to be effective mangers and innovators in a dynamic environment, on an ongoing basis, have required careful attention to be given to the MTM course development process.

As apart from the MBA courses and the existing “Engineering and Surveying Research Methodology” course, none of the MTM courses had previously been taught at USQ, a further challenge was that new material had to be written for these courses.

Another challenge arose from the desire to equip managers of technology to play a significant role in determining the direction of their organisations in a dynamic environment, at both a strategic and operational level. To do so, it has been necessary to both keep the course objectives and material suitable for management students at a postgraduate level while providing sufficient detailed information to enable them to understand operational issues. In time, further courses at the more detailed management level might be needed to meet this need (refer example discussed below).

Finally, the author, who has been responsible for developing a number of the courses, came to the university directly from industry and therefore had to meet the challenge of learning much in a short period of time.

Meeting the Challenges

The first step in meeting the challenges was to form a group responsible for developing the courses in the MTM. The author is a full-time member of this group, and has the support of a number of experienced academics who provide input into the development process and give feedback.

There has also been close liaison with the university’s Faculty of Business, which has also provided assistance, input and advice. In addition, there is close liaison with an Instructional Designer from the university’s Distance Education Centre to ensure that course material is based on sound flexible learning practices, stimulates active learning and meets university guidelines.

An example of this development process is the course “Asset Management in an Engineering Environment”, which deals with the life cycle management and economics of technological assets.

As with the definitions of “technology” and “technology management”, one of the first tasks in developing this course was to define what was meant by those assets that should be managed by an engineer or technologist – the “technological assets.”

A further challenge was to decide on the way in which the course should be organised and presented to meet the course objectives and to challenge learners. It was decided to use a strategic approach to asset management, starting with the life-cycle outcomes to be achieved then following with the methods and tools, such as economic decision-making and information systems, to support this process. A final section – combining these approaches into an integrated whole - is aimed at equipping asset managers to operate in a dynamic environment.

A textbook, based on infrastructure management, was selected. However, the variety of technological assets, and the need to challenge advanced learners, meant that other study resources were required. Thus, the course uses guided research of the type discussed previously – reflection, research into key issues (supplemented by a series of questions to prompt the research process), development of opinions and problem solving. Extensive use is made of on-line research to supplement written material.

The availability of considerable information on this topic has presented another educational challenge – what to keep and what to omit so that the higher level needs of management students at a postgraduate level could be met, while also providing sufficient detailed information to enable the students to understand operational issues. One solution has been to adopt the “essential, important, background and other” classification of study material discussed previously. Development of a future subsequent course in the more detailed aspects of asset management might be a further option.

Development of this course has been a steep learning curve for the author, whose next step is to deliver it in the first semester of 2004.

Implementation of the MTM

The MTM aims to be a postgraduate degree that combines expertise from the disciplines of business, engineering and surveying into an integrated package aimed at the innovative management of today’s and tomorrow’s technology based organisations. It combines both theoretical and practical aspects and therefore should appeal to the modern manager of technology.

As discussed previously, it is being initially delivered to practising engineers and technologists through part-time distance education, supplemented by on-line discussion and research. Possible future full on-line delivery may be used to improve course delivery and flexibility.

While the MTM can be seen as an integrated program, its courses are also being developed as “stand alone” packages that can be studied independently of each other. These courses are being developed in a modular fashion that permits selected modules to be offered as future short courses.

Conclusions

The Master of Technology Management and its associated programs are being developed in response to a changing world and changing demands on engineering and technology professionals.

Because of the developing environment in which graduates from the program will work, and because of the changing needs of managers of technology, development of the MTM will be a dynamic process. It has been a particular challenge to the author, who has joined the University environment directly from industry and has had to learn how to develop courses.

Conversely, the recent industry experience of some of the staff developing the MTM courses has lent enthusiasm and an understanding of the need for technology management and innovation, and has therefore – in combination with the knowledge of experienced academics - benefited the development process. As a result, it has been possible to identify and address any development issues, and in the process produce a balanced program suitable for today's dynamic technological environment.

Through overcoming the challenges of developing the Master of Technology Management, it is expected to develop an interesting and challenging learning experience for the student, and equip its graduates to be innovative; in tune with both the engineering and business worlds; and able to effectively, efficiently and proactively manage both existing technology and that of the future.

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Some considerations for the sustainability of engineering education

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Abstract: *Engineering education in Australia and around the world is facing many challenges and there are justifiable concerns about whether it can be sustained in its present form and with current funding levels. The purpose of this paper is to discuss areas of concern and suggest possible ways forward. The main areas causing concern are increasing student/staff ratios, frequent reviews and course changes, lack of pre-requisite knowledge by students, cost of laboratories and uncertain funding. The need for increased efficiency is discussed and the means of achieving this.*

Keywords: *engineering, education, sustainability.*

Introduction

The concepts of sustainabilty are normally applied to engineering practice such as design, development, production and maintenance. However, there are pressing reasons for considering sustainabilty in the context of engineering education. This is because many tertiary institutions have seen a great reduction in their funding relative to the number of students. At the same time many institutions teach in much the same way as they did ten years ago and are therefore not more efficient than they were. Compounding the problem the last ten years have seen an increase in "accountability" that has been manifested by frequent reviews. These in turn have inevitably led to course changes as no review is likely to conclude that no changes need be made. As an example consider the Department (now School) of the authors. In the last 5 years there has been a review of Engineering that resulted in major changes to the courses, an IEAust accreditation visit, a review of the Department and about to take place an Australian Universities Quality Audit Review.
In 1999 the Department had 20 teaching staff and currently has 14 with no reduction in student numbers. It might be thought that the Department's finances should therefore be healthy. In fact there have been no funds available for buying equipment (other than computers) for several years. At the same time the various reviews "encouraged" more project work in the lower years so that each staff member has an additional (on average) eight projects to supervise in each semester in third year. These activities are not efficient in staff time though it is not disputed that such projects are beneficial to most students. Thus there is less funding and teaching loads are significantly higher. Finally there is no indication that there will be any increase in funding levels, rather they may reduce further in real terms. The

question is therefore relevant, "Is engineering education sustainable?". The areas of concern will be discussed in more detail and then some suggestions on what may be done will be made.

Areas of concern

The main areas of concern of the authors are considered below. In different institutions there may be other more particular and local issues. Also the student intake may be very different and bring other issues. However, it is expected that those discussed below will be of general interest.

Student/staff ratios

One of the authors has been teaching at universities since 1972. During this time student staff ratios have continually increased. Many universities have very large first year classes (>500 students) and yet in subsequent years have very small classes because of the range of options/electives that are offered. Thus first year classes are regarded as a financial bonanza that helps fund the smaller higher year classes. This does however overlook the fact that first year students often need more attention and struggle with the transition from school to university.

The inevitable conclusion has to be that staff cannot spend as much time with individual students as they once did. Staff do not get to know students and are perceived as distant and not interested in the students. It is therefore not easy to spot students at risk, either of failing or with serious personal problems.

Frequent course changes

The time spent by academics on preparing good material depends on the length of time that the material will be current. If an academic is in charge of a unit for a significant time (say five years) then the unit may be developed to a high degree. There is the problem of the teacher becoming stale but the stability of teacher and content helps justify time spent on producing good teaching materials.

In recent times the need for "accountability" has resulted in numerous reviews that often result in course changes. The possibility of having the same lecturer teach an essentially unchanging unit for five years is becoming a distant memory. The consequence is that with other increased demands on time (eg. more students) very little effort is put in to producing good materials. For those few staff who attempt this there is soon a loss of heart at the small reward for a lot of effort when the material is no longer used.

Students' prior knowledge

Both of the authors have extensive contacts with first year engineering students. All first year students at UWA take a unit Engineering 101 which has material on statics, dynamics and dimensional reasoning. For many years we conducted a test without warning in the second lecture of a similar but now discontinued unit. The test used was the Mechanics Baseline Test (Hestenes 1992) which consists of about 30 multiple choice questions on basic mechanics. The results of one such snap test are shown in Figure 1.

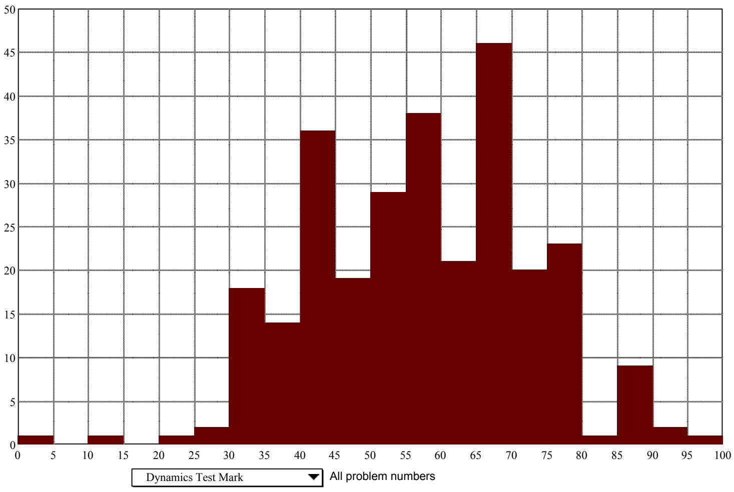

Figure 1 Mechanics Baseline Test scores from a snap quiz in a lecture, Feb 1999.

It was alarming to find that, though the students had all achieved high marks in their school leaving exam on Physics, 20% of the class scored under 40% in this exam. This result has several possible explanations.

* The students may not have been taught the material though this is extremely unlikely.
* The students never understood the material and the exam questions did not probe their understanding.
* The students crammed for the exam, knew sufficient on the day, but had no continuing knowledge of the material.

Whatever the explanation a first year lecturer has to accommodate what students know sitting in the lectures. This is becoming an increasingly time consuming task and students can feel "lost" very early in a unit. The question of how to determine if pre-requisite knowledge is present and what to do to rectify any shortfall demands time that is in short supply.
As an aside, our students' performance on the Mechanics Baseline Test was quite similar to that of first year students at Harvard, where the test was developed.

Laboratories

In a previous paper we wrote,

> "One of the major changes in engineering education that has occurred over the last forty years relates to laboratories (hereafter called labs). Stone remembers, as a student in the 1960's, undertaking 3 labs a week and each one required a report. Today both the number of labs and the amount of writing have been reduced. There appear to be several reasons for this. Lab hardware is expensive - there are not sufficient funds for major pieces of equipment such as turbines. The student/staff ratio is low in a lab and it is hard to justify such "inefficient" teaching in the current tight financial conditions. Any academic who develops new and innovative labs is unlikely to be rewarded. Labs do not count for much in promotion applications. There is therefore little incentive to focus on labs.... The use of virtual labs has been increasing." (Turnbull 2001).

Nothing has changed and engineering students are completing fewer labs and many of those are virtual labs. It is the experience of the authors that students do not have basic skills. As an example many students in third year did not know how to measure the frequency of oscillation of a torsional vibration. Engineers need hands on experience of real equipment.

Possible solutions

It may be thought that little can be done. For many academics that might be true since their teaching loads and other demands on their time do not allow the possibility of investing effort in looking for solutions. However the authors have been able over several years to make significant and time saving changes to the way they teach.

More efficient teaching

We have been using computer based tutorial systems in large first year engineering classes since 1995 (Scott 1999). Networked, monitored tutorial systems were fairly unusual when we started but are now quite common. Some features of our approach, however, are still not widely used:

* Our tutorial problems are somewhat diagnostic. When a student enters an incorrect answer, the computer system tries to give some feedback that may be helpful. We implemented this part of the system in a very simple way, by having each problem calculate both a correct answer and also a range of common wrong answers, from the randomised problem parameters. The maths for the wrong answers was developed by talking to students, by looking at past exam papers, and through long teaching experience.

  Why is this efficient? Because anything the computer system can help a student with is something that does not require human intervention.
* We run a messaging system called The Forum as an integrated part of the tutorial system. Some design decisions about the behaviour of The Forum have proven to be very helpful. For example we have structured the "discussion threads" so that there is exactly one thread per problem in our large problem set. This has worked very well because when a student is stuck on a particular problem, there is usually some quite specific discussion in the bulletin board for that problem. If the existing questions and answers are not helpful, a student can always post a new question at the end of the existing ones. Staff give such messages a high priority because The Forum is a very efficient form of teaching. A question posted by one student in a class of 500 – and the response from staff – can be viewed by all other students in the class. A given question need only be answered *once*! So the small staff effort to make answers swift and cogent is justifiable.
* Each year we must book tutorial times for our large first year class in a shared computer room called the Maths Computing Laboratory. It is a large hall with 128 web browser terminals. The tutors – mainly academic staff – do not dominate the room but instead wander about giving assistance. By observing the way that students actually work we have achieved some efficiencies. For example we do not generally book tutorial hours in the afternoon because students have historically not attended. They prefer to work in the morning. So we put up to three tutors into morning sessions and reduce the total number of tutorial hours. We respond to demand on a weekly basis and can move tutors if very full classes are seen.

This form of tutoring was designed to produce better outcomes but has had the added bonus of reducing tutoring time compared to the smaller group tutorial. We save up to 70% on tutoring time with better outcomes and higher student satisfaction.

Sharing of materials

It has been pointed out that there are about 30 universities in Australia with first-year dynamics courses. Most use one of two common (and excellent) textbooks but there is also usually some additional course material: a set of printed notes, a web site, or perhaps some on-line tutorial problems. In principle some of this teaching material could be shared between universities. Why does this rarely happen in practice?

This problem has, rather unkindly, been called the "not invented here" syndrome. Academics do have an independent streak but that is not the sole driving force behind the continuous re-invention of course materials.

We think there are two main reasons. The first is that university teachers are not generally suffering from a *lack* of teaching materials. This need can arise as a result of course revision but what is then needed are teaching materials *adapted* to match the new course. The degree programs at the 30 universities are all somewhat eclectic so the teachers are unlikely to find a set of course notes that is exactly right. First-year students, likewise, do not generally suffer from a lack of course material. What they need and desire, really, is *more contact with staff* to help them understand the material they already have.

In the case of tutorial problem sets there is the related problem of software compatibility. If two universities both have the same tutorial system, eg. WebCT, in theory the staff can share problem sets. But more often the software is not identical and it is not trivial to re-implement a problem set.

The other reason course material is not often shared is the problem of quality control. Our experience is that a single error in an assessed problem on our computer tutoring system causes a cascade of student worry and loss of confidence in the whole tutorial system. Students quickly begin to attribute all lost marks to system errors. This has a knock-on effect on overall class performance because if confidence in the tutorial system fails, morale also drops. If UWA agrees to swap a problem set with Griffith University, as an example, and assuming that the compatibility issue is resolved, what can we do if the set we receive is unsatisfactory? Or what can they do if our problem set has weak diagnostics or there are gross errors?

Because it is likely that continuous course review and revision will occur at all universities, we cannot expect long term congruence between any two courses at any two universities. Perhaps the best we can hope for is not cross-sharing but cross-injection of fragments of course material. At a given instant in time it may be possible for two staff at two universities to swap certain problems or notes. If the material is adapted and inserted into the canon of course resources at each site, there is some chance that the material will survive several course revisions, and thus realise an efficiency. However it should be noted that this is all dependent on the two universities having a flexible approach to intellectual property.

On-line laboratories

It seems that the cost of developing new laboratories and the lack of recognition (in promotion) of those who develop them will mean that little can be done. At UWA we have however found a means of developing new laboratories as part of an investigation of the use of on-line laboratories. Thus the development of such laboratories is part of the project work of students. We thus "kill two birds with one stone". At the same time such laboratories can be used off-line in a more conventional way.

The future of on-line laboratories is uncertain but there are clear advantages for students who are unable to attend labs on campus. Also it is possible that very expensive labs could be made available to other universities. In a previous paper the issue of the importance of hands-on laboratories was discussed (Turnbull 2001). An assignment was set requiring students to discuss the use of on-line labs and they were given the opportunity to be both in the lab and on-line. It was notable that all students indicated that the lab was essential to the full understanding of the unit (on vibration) and that the change from being on-line to seeing and touching the "real thing" was significant.

Stable course content, (and the problem of changing server packages)
There have been many changes to our tutoring system since 1995. There was a review and inevitable reconstruction of our first year program in 1999 (implemented in 2000). Also, because of changes to computer systems we have had to re-write our server package three times. Despite all these changes, however, we have been able to preserve some valuable results of previous work. Our dynamics problem set, written by Stone in 1994, has been preserved. The intellectual effort of devising good problems, and the associated diagnostics, has been repeatedly "ported" to new computer platforms and "recycled" as part of new courses.

This highlights two efficient activities: writing good problem sets, and porting/recycling. The two are linked because if the technology required to enable a good problem set is *too sophisticated*, it may not be feasible to port it to a new server platform or recycle it into a new course topic.

As a case study, at our university many staff are now using the commercial package WebCT. Anyone writing teaching material for WebCT will work with the existing, supported problem types such as multiple choice. Although not terribly useful in engineering, at least this problem type is simple enough that it should be easy to port a given problem set to some other package. In our case we rejected multiple-choice very early on and instead have concentrated on problems with numerical answers and diagnostics. These are not supported by WebCT nor, as far as we know, by any of the five or more other commercial tutorial systems. We have only been able to preserve the investment of time in our problem set because *we are also in control of the software development of the required server systems*.

Our message here, really, is "do not be afraid to write your own server package" if you want to have a unique interface for students. Writing a server package commits a staff member to a certain amount of yearly maintenance but gives independence from arbitrary institutional decisions, and allows preservation of unique problem types and other teaching development work.

Better links with schools
The problem of students not having pre-requisite knowledge is being overcome by the abundance of WWW based material. Thus within our school we are able to refer students back to what they were supposed to have covered. In some cases we just give a reading list based on WWW material to fill in the omissions. It therefore seems that a similar approach could be used if school material was similarly available AND the university lecturer was aware of it. However this is another time consuming process and it may never come to the top of the list of things to be done.

Conclusions

This paper has raised concerns about engineering education that question whether it is sustainable. At the same time some suggestions that may help have also been made. As is frequently the case individual lecturers will prioritise their tasks and act accordingly. We have been able to introduce new methods of teaching because our university encouraged us to do so and we work well as a team. We have the greatest sympathy for those lecturers who feel very alone and without support. The next decade will be of great interest as changes will be made/forced. It is an open question whether engineering education is sustainable in its present form and with its current financial constraints.

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Meeting the educational demands of the South Australian automotive industry

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Abstract: *The largest employer in South Australia is the automotive engineering sector. This thriving industry, which is now going through a rapid period of expansion, produces billions of dollars worth of exports. This healthy situation has developed an immediate need for skilled workers that cannot be met by the state's tertiary education institutions. While in the distant future there may be a reduced demand for the overall numbers of employees, because of the need for more efficient working practices workers will need to be smarter and more qualified to implement these practices, thus continuing to place higher demands upon tertiary institutions.*

The School of Mechanical Engineering at the University of Adelaide has also seen a steady increase in the number of students who favour a mechanical or mechatronic engineering vocation. However, engineering is a vast discipline and the knowledge and expertise that students are expected to develop during the course of their degree, so that they are prepared for a multitude of possible career choices, is extremely wide ranging.

This paper presents a discussion for the need and proposed structure of a more specialised degree program, in which the increasing demand for a smarter workforce from the automotive engineering industry can be met by specialised Australian graduates.

Keywords*: Automotive, Vocational, Career.*

Introduction

Background

Two years ago the author commenced work as a lecturer at the University of Adelaide. Supervising a final year project in which sixteen students raised finance to design and build a race car quickly exposed him to the automotive industry in South Australia. It was very surprising to see that with such a vibrant and significant engineering sector, none of the South Australian universities offered a formalised degree program that enabled students to specialise in this area. Numerous meetings with industry (refer to acknowledgements) followed to establish whether there was indeed a need for such a course or a means in which engineers could graduate with a more specialised understanding of the industry. More recently (presumably because of drawing similar conclusions) the Department of Further Education, Employment, Science and Technology of the South Australian government have established a skills initiative to address the shortfall of appropriately qualified and skilled automotive labour on a broader scale, looking at school leavers, trades people, engineers and management. The author is also a task force member of this initiative and draws some of his observations and conclusions from this forum.

The South Australian Automotive Sector

South Australia has a booming automotive engineering sector, fuelled by the recent successes of its two major automotive manufacturers (Holden and Mitsubishi) and the subsequent knock-on effect to their local subcontractors and suppliers (too numerous to mention in the context of this paper). Many of these suppliers are also independently successful, contributing towards an automotive export market worth billions of dollars annually.

In the Advertiser last year, Kelton & Duffy (2002) published a front page article detailing Mitsubishi Motors Australia Limited's (MMAL) acceptance of a State and Federal government investment incentive of $85 million, sealing a total investment commitment (from Mitsubishi, Japan) of nearly one billion dollars in total. This ensures the design and development of two new vehicles for 2005 and will establish an Adelaide based R&D centre.

In January of this year Holden announced, in various press articles and on their media release web site (Laird, 2003), one thousand new jobs for its Elizabeth manufacturing plant (in Adelaide) and the introduction of a third shift to satisfy its massive expansion program that will increase the number of models they now produce from 28 to 35. Holden Chairman Peter Hanenberger, stated that "Holden was on track to becoming a global car company driven by Australian know-how and expertise".

Many more continuing and emerging success stories of South Australian automotive industries can be quoted, such as Castalloy's production of wheels for Harley Davidson, or Schefenacker's lions share of the world rear view vision market, but the list would be far too long for the context of this paper. In short, the local industry is booming.

A joint State and Federal government press release (Vaile & Minchin, 2000) reported that in 1999 Australian automotive exports amounted $3.8 billion, which was a 36% increase on the previous year. This rose to $4.2 billion in 2000 (Vaile, 2001) and $4.9 billion in 2001 (Vaile, 2002). Automotive exports now rank ahead of beef, wheat and wool, and are just behind gold and iron ore in terms of export value. The largest export markets include Saudi Arabia, the United States, New Zealand, the United Arab Emirates and Kuwait. It was also estimated that the figure would rise to $6 billion in 2002 but figures to confirm whether this became so, were not available at time of writing this paper. It can however be seen from Figure 1 (extracted from the FAPM 2002 Industry Products Directory) that there is a strong trend to indicate that the industry will continue to grow from strength to strength.

The previous paragraphs illustrate that the Australian automotive industry is clearly successful in terms of its domination of the domestic market and its export figures, but is still small by world standards. Its ability to survive and prosper in the world market place is largely due to a "boutique car manufacturer" attitude that addresses the customer desire to own an apparently unique car. Because the cars are manufactured to order, an extensive range of colours, trim options and accessories ensures that few cars are identical. This in itself requires a dynamic approach to keep one step ahead of competition and the need to demonstrate flexibility and innovation in terms of design and manufacture. In order for this success to continue, more efficient working practices will need to be introduced that, while ultimately leading towards a reduction in overall staff numbers, will substantially increase the need for skilled and qualified personnel. The Australian automotive workforce needs to become leaner yet smarter. This is not only the case for the prime manufactures, but also for the subcontractors who are being forced to accept more and more responsibility for the cost, design and quality of their deliverables.

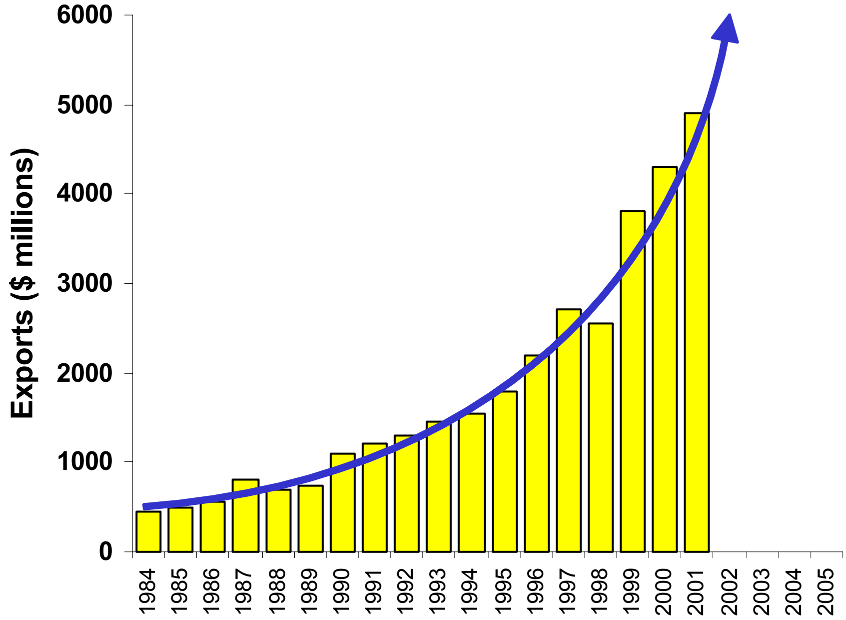

Figure 1: Australian export figures and trends

This need, amidst a national shortfall of specialised and qualified automotive engineers and tradesman, has increased the incestuous practice of companies poaching skilled labour from closely related industries, at a scale that is producing some angst and ill feeling. These industries are not necessarily competitors, but often from a common chain of contracting and subcontracting partnerships, and so the problem often shifts up and down the same supply chain.

The Australian skilled and qualified employee resource pool needs to grow. Importing skilled labour is costly (although often resorted to in desperation), time consuming and risky. It is also counterproductive for those who may seek a career in the automotive industry, but do not have the opportunity to specialise.

Australian engineering graduates are regularly recruited by automotive employers, but it is generally believed that they do not have sufficient specialised knowledge to become productive in a sufficiently short enough time frame. The following sections therefore detail some of the steps and propositions that the author is making in an attempt to address this.

The first steps towards producing specialised engineers

Formula SAE

Obviously most Australian universities that offer mechanical engineering courses show some interest in automotive applications. To complement the theoretical content, students often participate in practical laboratory sessions, or choose to be involved in design or research projects with an automotive application focus.

However, to place the vocational value of these projects and lab classes in perspective, it must be remembered that engineering is a vast discipline and that students must develop a broad range of engineering attributes to prepare them for a multitude of possible career choices. Consequently, while these methods may encourage student interest, the automotive engineering exposure is minimal and does little to prepare them for the specific engineering practices of an automotive engineering company.

One student project is, however, proving to be an invaluable exception and has won immense support and praise from the top four Australian car manufactures (Mitsubishi, Holden, Toyota and Ford). The Formula SAE (Society of Automotive Engineers) project (now regularly patronised by over sixteen Australian universities and invited overseas universities) exposes students to the realities of automotive engineering. In this project a team of students are required to raise funds, design, build and compete in a Formula style vehicle amidst strict design regulations and time constraints (
Figure 2). Students gain first hand experience in:

- working to design constraints and specifications,
- working to a budget,
- working to strict and real deadlines,
- team management,
- methods of manufacture,
- the value of modelling and prototype testing and
- the assessment of product performance against stiff competition.

Representatives from the event sponsors (Mitsubishi, Holden, Toyota and Ford) regularly tell participating students that involvement in Formula SAE is valued as highly as an initial year of on-the-job training.

While this is an encouraging step in the right direction, few universities nationwide offer a formal recognised structured program that is geared towards the specifics of an automotive engineering vocation. To the author's knowledge, and at the time of writing this paper, only RMIT offer a Bachelors Degree in Automotive Engineering. Nothing along these lines (or towards similar goals) exists in South Australia, a state rich in automotive interests.

Figure 2: The University of Adelaide 2002 Formula SAE car

A New Automotive Engineering Elective

In pursuit of the goal to improve the preparation of undergraduate students for a career in automotive engineering, the University of Adelaide has now added a final year elective subject to its fourth year curriculum – Automotive Engineering. This subject, with a strong vocational focus, is not intended to theorise, but to expose the students to specific design areas and the working practices of this engineering sector. Towards this end, industry experts (in most cases senior managers) present a series of lectures to the students. This has a number of advantages over the use of an academic lecturer, in as much as it:

- ensures an up to date perspective of current practices and relevant issues,
- allows students to empathise with experienced qualified automotive engineers,
- exposes students to their potential employers from the sector, and
- enforces that what is said, is what actually takes place.

This optional subject addresses company missions, design objectives, design philosophies, engineering practices, work-place practices, safety, environmental issues and quality assurance practices. On-going discussions with industry have, however, shown that while this subject has been extremely well received as an interim measure, their ultimate desire is for a fully recognised local automotive engineering degree program that allows proactive industry involvement. The following section therefore details the plans and proposal that the author has towards realising this requirement.

A proposed Bachelors degree program

For a university to accept a proposal for a new degree program, it must not only have a perceived value for the university, but must also be cost and time efficient as well as straightforward to implement. A totally new course structure and course content for each level would most probably be unacceptable, but also unnecessary.

As already discussed, automotive engineering has a strong synergy with mechanical engineering, and is probably best described as a specialised stream that incorporates disciplines from other schools of engineering (electrical, production, manufacturing and industrial design for example). However, the combination of these ingredients when blended, form a special brand of engineer who, while encumbered by a bureaucracy of procedures, standards and quality assurance systems (second in depth only to aerospace and military applications), will be expected to develop a high level of niche expertise while remaining creative, innovative and versatile throughout their career.

The fact that there is so much in common with a mainstream mechanical engineer and a dependence on many of the theoretical concepts that are taught in a mechanical engineering program, implies that an automotive engineering degree would not have to be too dissimilar to a mechanical engineering degree. It would however need to be tuned to address the peculiarities of automotive engineering practices and to address the directly relevant theories in more detail.

The first two (foundation) years can in fact be common to both automotive and mechanical streams. The third and fourth year would then require customisation to address specific automotive engineering requirements. To include the additional material, some mechanical engineering subjects must be sacrificed. While it may be argued that all third and fourth year mechanical engineering subjects have some relevance to the requirements of an automotive engineer, there simply won't be sufficient time to include it all. A five-year program would not be an attractive proposition for students and as a consequence, would be poorly patronised. This apparent problem may however be alleviated with a careful choice of subjects, so that all of the required attributes of a graduating automotive student are adequately addressed.

Table 1 shows a proposed course structure for an automotive engineering degree and draws comparisons with the mechanical engineering program. Its merits include sufficient similarity with the mechanical engineering degree to permit efficient and relatively easy implementation with minimal effect on staffing and timetable disruption. It is estimated that only one additional lecturer is required. It can also be seen that a necessity to remove pertinent subjects is significantly minimised by reducing the choice that students may normally exercise for fourth year elective subjects.

Year	Subject		Points
Level 1	All subjects are the same as BEng (Mechanical)		**24**
Level 2	All subjects are the same as BEng (Mechanical)		**24**
Level 3	Thermo-fluids 2	(same as Mechanical)	3
	Engineering and the Environment	(same as Mechanical)	2
	Heat transfer	(same as Mechanical)	2
	Dynamics and control 2	(same as Mechanical)	3
	Solid Mechanics	(same as Mechanical)	3
	Design and communication	(same as Mechanical)	3
	Manufacturing engineering,	(same as Mechanical)	2
	Power train Design	(Mechanical has Eng Maths III)	2
	Vehicle Electronics	(Replaces Elec. Energy Systems)	2
	Ergonomics for Industrial Engineers	(Replaces Aeronautics)	2
		Subtotal (level 3)	**24**
Level 4 Core	Engineering management and professional practice	(same as Mechanical)	2
	Automotive Design Project (part 2)	(same as Mechanical)	8
	Vehicle Dynamics	(Additional core)	3
	Vehicle Safety	(Additional core)	3
	Advanced Design Methodology	(Additional core)	2
		Subtotal (level 4 core)	**18**
Level 4 Electives	Choose 6 units from any other elective	***Subtotal (level 4 electives)***	**6**
		Total Units	**96**

Table 1: Proposed Automotive Engineering Degree Program

Choosing these newly offered electives on behalf of the student immediately adds a distinctive automotive flavour to a mechanical degree program. Minor changes in the third year curriculum will necessitate replacing some of the existing courses, but the consequences of these will be minimal, while substantially strengthening an automotive engineering focus. Electrical Energy Systems would make way for a more specifically focused Vehicle Electronics subject. Aeronautical Engineering would be superfluous to an automotive engineer and could therefore make way for Ergonomics for Industrial Engineers. Mathematics at level III has value, but is perhaps better suited to a research focused student more so than one with an automotive vocation focus. This would therefore make way for a subject on power train design.

A significant component of the fourth year mechanical engineering curriculum is the final year project, worth one third of the final year mark. This will continue to be the case for the automotive engineering curriculum, but each project, whether research based or industry focused, must have an automotive focus. It is also planned to sub divide the third year design and communication subject (common to both streams) so that automotive engineering students consider an automotive assignment. This may be an opportunity for third years to conduct initial research for a large final year project, such as the Formula SAE (which would only be available to automotive engineering students).

The proposed structure is also intended to bring together the strengths of The University of Adelaide and the University of South Australia. Discussions with their School of Industrial Design have been initiated to explore the possibility of a joint university venture.

Student Interest in Automotive Engineering

Towards the end of 2002 and at the beginning of 2003 there was a significant amount of press coverage in South Australia regarding the successes of Holden and Mitsubishi. Coincidentally, this year's student intake in the school of Mechanical Engineering at the University of Adelaide has increased by 31% when compared to last year.

Participation in the University of Adelaide's Formula SAE project is always over-subscribed with many students disappointingly being turned away each year.

Engineering electives usually attract between thirty and forty final year students from a crop of about one hundred or so. Over one hundred enrolled in the Automotive Engineering subject.
It is clear that student interest exists. The employers' needs for specialised engineers also exist. Only the local tertiary educational programs are missing in South Australia at this moment.

Conclusion and Future Plans

The successes of the South Australian automotive industry have been briefly summarised and the problems associated with an insufficiently qualified work force highlighted. Local South Australian undergraduate students are demonstrating interests in automotive engineering, and should be an obvious target for employers. However, few opportunities exist for them to specialise and develop the appropriate skills and attributes that would enable them to become more immediately productive and hence more attractive to automotive industry employers.

The University of Adelaide has now demonstrated a commitment towards improving the relevant skills of mechanical engineering graduates with its involvement in the Formula SAE program and the introduction of a specialised final year elective. The author is now actively working towards implementing plans for a Bachelor's Degree in Automotive engineering. Discussions with interested parties will continue as will the exploration of methods and levels of funding.

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Acknowledgements

The author would like to acknowledge the valued support of his Professor, Dr. Colin Hansen and advice from Mitsubishi, Schefenacker, BASF, The Road Accident Research Unit, TMP recruiting and the Federation of Automotive Parts Manufacturers. Valuable information has also been drawn from the ongoing efforts of the Department of Further Education, Employment, Science and Technology South Australian Skills Initiative.

Sailing off in a leaky boat: how some international postgraduate engineering students and their supervisors embark on candidature

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Abstract: *This study explores the learning and writing strategies used by two international research Master of Engineering students in the first six months of candidature. Using an interpretive case study approach, data from interviews and samples of the students' research writing were examined and revealed strategies consistent with those identified elsewhere in the literature. Several of these strategies appear to have contributed to the students' difficulties in meeting the academic writing demands of early candidature such as preparing their research proposals. These difficulties related to both the students' fundamental engineering knowledge and their ability to write about engineering research. This study provides insights into these students' responses to the engineering and academic literacy demands of their postgraduate study. It also strengthens the suggestion that some international postgraduate research students require additional time and structured educational approaches to 'stay afloat' in their transition to postgraduate study here.*

Keywords: *international students, postgraduate education, learning strategies*

Introduction

Many postgraduate research students in engineering are required to produce a research proposal in early candidature and this document may form a significant part of the evidence used to assess a student's suitability to continue. This assessment has greater urgency now with pressure placed on university departments for timely completions by these students, a situation sometimes at odds with their need to explore a chosen research field and gain the background knowledge and skills necessary to develop a sound research focus and approach.

There is some evidence that starting the research related writing process early in candidature contributes to the timely completion of a thesis (see for example Latona and Browne, 2001). However, many commencing engineering candidates struggle to understand the theoretical concepts, analytical methods and factual material they will need to conduct their research, and also require enhanced academic literacy to communicate effectively in their research arena. Furthermore, there is a tendency to view writing in engineering and related disciplines as 'being after the fact', that is as description of products or processes that are fully conceptualised before the writing takes place. Winsor (1994) challenges this view by providing evidence that engineering students use writing to generate ideas. A further, persuasive argument for the inter-relatedness of text production and knowledge generation in postgraduate research in general is put forward by Dysthe (2002) in her study of supervisors' influence on masters students' text production:

> *… the relationship between knowledge and language is a complex one, textual practices are closely intertwined with research process, and writing is both an individual and a social practice (Dysthe, 2002, p 499).*

While Dysthe did not specifically relate this relationship to engineering, it may in part explain the difficulties some international postgraduate students encounter in understanding and engaging in engineering research related discourse practices. The time pressures placed on students who are attempting to meet simultaneously both engineering knowledge and academic literacy demands in a second or subsequent language may create a situation in which it is impossible for a student to succeed in the given time frame.

This situation is important to address because production of research related written text is the single most important way postgraduate students present themselves as participants in their research communities (Mullins and Kiley, 2002; Cadman, 2002). Consequently, an unsatisfactory research proposal may threaten a student's candidature. In this regard, the integration of language and learning specialist programs within engineering postgraduate training provides greater opportunities to foster students' academic research literacy and to recognise and address problems early (see Melles, 2002). The present paper was motivated by the experiences of two struggling international Master of Engineering students in an Australian university, their supervisors and their ESL lecturer.

International students' learning and writing strategies

Studies into the international postgraduate experiences and performance of students provide insight into the strategies used with varying degrees of success by these students as they engage with the discourses of their disciplines through reading (Benson, 1991), writing (Leki, 1995; Chandrasegaran, 2000), and oral communication (Ferris, 1998; Morita 2000). A seminal case study by Leki (1995) reveals the coping strategies of international undergraduate and postgraduate students engaged in discursive writing tasks. These strategies worked to greater or lesser effect for the students involved.

A feature of Leki's study that makes it particularly relevant to the present work is that it investigated students' strategies used to produce authentic discipline writing tasks rather than ESL classroom tasks, which Leki suggested are easier, and that her study included postgraduate writing. However, as in the other few studies that have explored international postgraduate ESL students' writing (Angelova and Riazanseva, 1999), Leki's study was conducted on students in a US university and across disciplines, where the graduate school curriculum is considerably structured. Very little research has looked at international postgraduate research students in an Australian university context, where their assessment relies very heavily on production of a written proposal and thesis with little or no coursework component; negligible attention has been given to the postgraduate writing of international engineering students in Australia.

The purpose of this paper is to provide insight into the language and learning experiences of these international postgraduate engineering students in the early stages of candidature. The specific aim of this study was to identify the strategies used by these students to select and use engineering content information for their research related writing tasks. The location of this study exclusively within the engineering postgraduate learning context may render its findings particularly useful for international engineering postgraduates and their supervisors.

Method

The two Masters of Engineering students who are the focus of this study attended a semester long bridging program that is compulsory for all commencing international postgraduate research students at The University of Adelaide (McGowan et al, 1996; Cargill, 1996). The program curriculum moves students through a series of developmental writing tasks, specifically a critical review and literature review, culminating in the production of a draft departmental research proposal. This document, or a refinement of it, is used to meet the University's requirement to submit a research proposal within six months of commencement of candidature. Both students had attended the classes and both had been identified by the ESL lecturer and their supervisors as having significant difficulties in completing a research proposal. Neither student had successfully completed his research proposal by the end of the program or in time to meet the University's six month deadline.

Sources of data included student interviews, oral and written communication with supervisors, observations of students in the bridging program class, student consultations, documents produced for the bridging program, and supervisor feedback on those documents. Each student was interviewed once; each interview lasted approximately 1.5 hours. The interviews were unstructured, and were focussed around the following three questions:

- How did these students' prior academic experiences prepare them for the writing demands of their candidature?
- What problems did these students encounter in meeting these demands during the first six months of their candidature?
- What strategies did these students use to overcome these problems?

Data analysis

The study used an interpretive case study framework where data are interpreted in terms of an existing theory or construct (Merriam, 1998). Data interpretation was informed by coping strategies that emerged in Leki (1995).

Findings from interviews

Louis, aged 25 and Tariq, aged 23 obtained undergraduate engineering degrees outside Australia. Both were ESL students, although Tariq attended an English medium university for his undergraduate study. They gave remarkably similar accounts of their past and current experiences, described their undergraduate performance as 'average', obtained IELTS scores of 6.0 in their home countries, had prior educational experience of lectures and labs only, and their undergraduate courses demanded a great deal of homework but almost no discursive writing. Homework involved calculation and lab reports written in a prescribed manner, which in Louis' case included using prescribed wording. Both came to Australia because they wanted the experience of living and studying in another country.

The interviews revealed that the students used seven of the fifteen strategies identified by Leki (1995). These related to managing information and language, and controlling demands on themselves. Data from their writing indicated that the students used three additional strategies in response to supervisors' and lecturer's written feedback.

Managing information: clarifying and focusing

Both students attempted to clarify their research writing by seeking guidance from their supervisors. Tariq explicitly stated that this did not help. 'At first my supervisors gave a lot of suggestions about readings but they were too hard. I asked them what I should read and what to avoid. They made suggestions. Still even suggestions were too hard – especially I could not determine how the readings related to my project. I tried to see how they related but couldn't'. Tariq also eventually decided to discuss his work with other students to get 'different ideas', which is another way students exhibited clarifying strategies in Leki's study.

Louis used what he called a 'clarifying' strategy, developed in his undergraduate years 'to extend my knowledge'. It involved standing in the library stacks looking for helpful books: 'I select interesting titles that might be helpful'. He looked for 'the big words' in the title and then at subtitles, pictures and diagrams; if a picture was related to what he wanted to know he read paragraphs around it. Louis also pointed out that he solved most of his problems by himself and only occasionally asked his supervisor or other students for advice.

To address the writing demands of a research proposal, the students identified elements of their project work in which they could develop greater depth of knowledge. Tariq changed the information gathering strategy he used at the beginning of his candidature because he felt he was looking at 'a too big picture and not focusing specifically on the project.' He took his original approach because he joined an existing project where several important stages of the research had been completed. 'In the beginning I told myself that if I do not study the whole things I will not be able to find my way because my project is related with so many stuff – even the physics so I am study physics to see the parts that are related'.

Louis chose to focus on subject content by extending his knowledge of vibration, which he believed 'will result in a better research proposal'. Louis concentrated on learning difficult information, but his strategy may explain a problem he had misappropriating others' words in his academic texts: 'Sometimes a paragraph is beyond my knowledge so I just write it. Over time I will absorb this unfamiliar type of information. For example, if I'm reading some research and don't understand why an experiment was conducted in a particular way.' Louis' focusing strategy appears similar to Leki's 'using current or past ESL strategies', but it was initially aimed at focusing on needed engineering information. Only after Louis thought he might have found the information did it become a language development strategy. He also looked for similarities between the way an author 'did things' and his own project. 'Sometimes, for example a computer program is the same but article uses it for different subject, so I think it's related.'

Managing language: looking for models and using past or current ESL strategies

Louis used these strategies to develop his written language skills, even before he came to Australia. When looking up texts, he picked out what appeared to be related paragraphs by the terminology used. 'Sometimes I appreciate word combinations in articles and write them in my notes. Sometimes this will mean I can then write something better. Sometimes word is out of my knowledge and I learn it for the first time.' He decided that information was relevant to his research by identifying key words. He also pushed himself to read the original English and not a Chinese translation, despite his friends' suggestions, because he wanted 'to get used to the English'.

Louis took notes verbatim while he read text. 'When I see something I like, first I write out in my notebook, then I make some changes… By the end of the week I put everything together and then change the writing to make it smooth by connections. I don't know if it's OK when it's finished.'

Controlling demands: managing workload and life, and regulating cognitive load

Tariq identified a 'danger' in postgraduate study; without specific assignments that have to be done, he found himself wanting to say 'I'll do it later' … 'it's easy to just exit my study'. Louis worked very hard and then felt justified in taking a rest: 'Sometimes it takes too much energy to do English language writing. I work long, maybe a whole day, then I take a rest.'

One of Tariq's strategies for moving forward was to work out, by himself, the relation between mathematical methods and computer programming. 'No one else will do this for me; I will have to work out the relationships myself. They're not going to do this for me.' This approach meant that he was consciously deferring his attention to this singular task until he was satisfied he could make these appropriate relationships.

Louis found his first three months in Australia very difficult for personal reasons and was aware that this interfered with his ability to get on with his work. Eventually he was able to focus on his studies but suspected it was then too late to finish his research proposal on time.

Other findings from interview data

Interestingly, both students found writing easy in their undergraduate study back home, but very difficult here. Both identified the transition from undergraduate to postgraduate study as the main contributor to this difficulty. According to Tariq, nothing he experienced in his studies back home prepared him for the way he would have to work here.

Both students expressed confidence in their current strategies. Louis' believed he was using the best strategies: 'These are the only way, in my kind of view, you can get best result'. As for meeting the writing requirements of their postgraduate candidature, Tariq felt he could not have produced a research proposal in six months. Jumping into a running research project meant he had a lot of catching up to do. 'The [bridging] program helped you to understand what you had to write about and how to write it. But I could not make links between all the parts of my project. Some parts had very complex mathematical solutions and I could not get them.'

Findings from other sources

Supervisor communication with the ESL lecturer early in the semester clearly demonstrated the confusion that can result when students present an array of difficulties:

> [His review] seems very jumbled and I'm unsure whether this is due to his language skills or lack of understanding.. Some of the questions [he] asks me also lead me to believe that there is some obstacle that prevents him grasping the simple concept of what I am asking him to do. Again, I cannot determine whether this is a language matter or lack of technical familiarity.

Examination of the other sources of information related to the students' first semester of candidature reveals instances where students appeared to be acting on the strategies described in the previous section, and additionally on Leki's strategies of accommodating and resisting teachers' demands. Louis' supervisor asked him to write an FEA report with very specific instruction for the report structure: 'The report should contain an abstract, an introduction, a method, results, discussion and conclusion.' Louis' unusual disengagement of words from their meanings and context, as evidenced in his 'focusing' strategy use, led him to produce a report with the required subheadings but with inappropriate text, as illustrated in Table 1.

Student's text	**Supervisor feedback**	**Student's strategy**
Abstract The simple rectangular fixed plate experiment for natural frequencies, the ANSYS program simulates the testing procedure and obtains the precise results.	Titles OK but content is in error Not an abstract: should be very short, concise overview.	Accommodating teachers' demands Also Louis' 'focusing' strategy resulting in meaningless use of word 'Abstract'.

Table 1: Illustration of Louis' focusing strategy use

The problem presented in Table 1, was partly addressed after Louis worked with his ESL lecturer to meet feedback expectations on a subsequent draft (Table 2). However, Louis' final research proposal reverted to copying others' language and showed inadequate grasp of research related engineering concepts.

Student's text	**Supervisor feedback**	**Student's strategy**
Abstract Modal analysis is used to obtain the natural frequencies of vibration of a structure, and it is very important to study the vibration modes. The discipline of modal analysis is divided into two areas, analysis and experiment…However, in the use of finite element techniques it can supply more accurate natural frequencies and verify the experiment results, furthermore, finite element methods can analysis more complicated structures that cannot be predicted by classical mathematical models	Louis, this is much <u>better</u>.	Using current experience or feedback to adjust strategies

Table 2: Initial response to supervisor feedback

Louis also received many hours of instruction concerning the appropriate use of source materials in his bridging program. He resisted these demands and continued to rely on his focusing and past ESL strategies, which resulted in copying from sources. Louis had no explanation for this resistance except that he found writing very hard.

Another example of resistance to supervisor's demands was found in Tariq's drafting of his literature review and subsequent research proposal (Table 3).

Student's text	Supervisor's feedback	Student's strategy
The first stage (Preliminary) of study one was conducted to develop a numerical model to optimise the design of the entire device…This stage compared the numerically predicted results with those experimentally measured…The next stage, study one was concerned with optimisation of the various parameter…The second stage of study two of this project applied to analysis tools developed in stage 1 to more…	Each of the project stages should not be considered separately. The literature review should flow from one to the other via a logical progression, highlighting the advances or different approaches taken at each stage.	Resisting teachers' demands

Table 3: Resistance to supervisor's demands

Supervisor further stated the following on a page of written feedback:

> …At the end of each stage of work [in large project] a report is required and hence the reports are titled Stage 1, Stage 2 etc so that the work in the reports can be compared with the aims and deliverables for each stage of work. When reporting on the work, or including it in a literature review it is necessary to consider which physical system or analysis methodologies have been examined. These are of much more relevance to a reader not familiar with the work. Titles such as Stage 1, Stage 2 etc do not convey any information.

This message was reinforced by the ESL lecturer, who pointed out that his literature review was very confusing to read with its references to these stages. Tariq resisted this advice and continued to refer to these stages of the larger project and prior reports throughout his subsequent research proposal drafts, resulting in the following feedback (Table 4).

Student's text	Supervisor feedback	Student's strategy
Stage one (Preliminary) was conducted to develop a numerical model to optimise the design of the entire device…This stage developed a numerical model for predicting results…Stage one (Final) was concerned with …Stage two of this project was applied the analysis tools developed in stage 1…	Supervisor feedback does not appear to have been incorporated in the final version of documents (written on end-of-semester report)	Resisting teachers' demands

Table 4: Resistance to supervisor's demands

Communication between the ESL lecturer and supervisors indicated early concerns about the students' writing, particularly their copying from other sources and difficulties in grasping the purpose of research related documents despite their having received clear guidance. Several months elapsed before their difficulties with engineering concepts became clear to the students, lecturer and supervisors. Table 5 shows Tariq's ultimate attempt to express his knowledge in his own words in his research proposal. His supervisor's comments clearly pointed to his need for improved engineering content knowledge.

Student's text	Supervisor's feedback	Student's strategy
Different methodologies such as Modal Coupling Analysis, Finite element Analysis (FEA) and Boundary Element Analysis were considered as a modelling approach.	This is not a different approach to FEA. It is used with FEA. .	Using current experience or feedback to adjust strategies
A Modal Coupling Approach gives modal descriptions of the system components…	Not a good description. You must take notes during our discussion.	
The Modal Coupling Methodology can specify the acoustic impedence at the liner face.	Misinterpretation of what modal coupling theory does. Not clear how this is relevant.	

Table 5: Attempt to convey engineering knowledge in writing

Tariq decided to apply for an extension to his candidature on the basis of inadequate time available to finish a Masters degree. He used the time to strengthen his engineering knowledge relevant to his research area, while continuing to develop academic literacy for research writing. At the time of writing, Louis was indecisive about whether to apply for an extension, intermit or abandon postgraduate research study in Australia.

Discussion

Both students used a variety of strategies to deal with the writing demands of their postgraduate study, but they became increasingly aware that they were ill-prepared for the academic literacy and engineering demands of early candidature and had great difficulty writing enough that was meaningful. At the time of interview, Tariq had made a shift in his thinking about strategies, but Louis had not.

In the present study, there was a clear indication that the ESL lecturer and supervisors gradually became aware of content knowledge problems as the semester progressed. Many gentle suggestions were given to these students to provide them with opportunities to show capability. Finally, feedback showed explicit comments on the students' apparent lack of understanding of key engineering concepts related to their research projects.

The strategies Louis and Tariq used have been identified elsewhere in the literature. Angelova and Riazantseva (1999) found similar strategy use, such as resisting instructor's suggestions and problem-solving alone. Louis's strategy of copying promising text from elsewhere appears to reflect the tensions, described by Pennycook (1996), that are faced by ESL students who are told to use their own words and 'are at the same time required to acquire a fixed canon of knowledge and a fixed canon of terminology to go with it" (p. 213). Also, the views of Chinese students whom Pennycook interviewed were similar to those Louis held about using other people's words. Johns (1991) description of an ESL science student's English competency exam preparation shows strategies used included memorisation of TV conversations, dictionary entries and biology text. Like Louis, this student also described his approach as looking for models.

Interestingly, Louis and Tariq were not able to make use of the highly effective bridging program in which they were enrolled, when other Master of Engineering students in the program over the same semester performed very well. Tariq's comments that he simply could not use the writing information he received because his understanding of engineering concepts was so limited is an indication that there was a strong need for him to spend more time honing his engineering knowledge.

Its small number of participants limits the present study. However, it provides a depth of insight that cannot be gained by larger, quantitative studies. Louis and Tariq used many of the strategies Leki identified in her study, and this suggests the use of these strategies may be common to many international postgraduate students. If so, awareness of this could be useful in informing supervisors and ESL lecturers who work with students in the personal educational environment of postgraduate research.

Conclusion

Louis' and Tariq's approaches to addressing the writing demands of their postgraduate study presented a frustrating interplay of linguistic, learning, subject knowledge, and intercultural issues. These students are not unusual. The transition to postgraduate study in engineering, with its high demand for learning independence, for writers to operate within the discipline-specific research genre, and for students to complete their research proposals, research studies and theses within a restricted time frame, may prove too difficult for international students struggling with language and inadequate engineering knowledge in their research area. These students may be better served by, for example, Diploma or Coursework Masters programs that prepare students for subsequent research candidature or allow the opportunity to go home with a completed non-research qualification. This would ensure that international postgraduate students and their supervisors have a better chance to 'fix the leaks' before sailing into candidature.

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"I had this real feeling that it was a boys club"

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Abstract: *The engineering profession continues to experience difficulty attracting and retaining women. Gender equity programs that focus on women's training, socialisation and non-traditional 'choices' overlook the centrality of workplace cultures. This study reframes the issue, problematising the work context, rather than women themselves. A qualitative investigation of women's and men's experiences in a range of engineering disciplines, industry sectors and work locations has been conducted. This investigation found that women engineers do not leave the engineering profession primarily as a result of family responsibilities, or their lack of confidence, technical expertise, or interest in engineering work compared to men. Rather, a more significant contributor to their reasons for leaving the profession was a feeling of alienation within the prevailing workplace culture.*

Keywords*: women in engineering, workplace culture, equal employment opportunity*

Introduction

Workplaces are changing rapidly in restructuring economies, but equity and diversity remain elusive. Despite several decades of Equal Employment Opportunities policies in engineering, women continue to be under-represented compared to men as engineering students, faculty members and professionals. Engineering has the lowest female share of any broad field of study in Australian universities, and the rate of increase in the enrolments of women in engineering courses has remained at around 0.3 or 0.4% per year from 1994 to 2000 (Kryger and Agnew 2002:39). The proportions of female engineers are not increasing as rapidly as women within other male dominated professions, and there is a clear tendency for young women to drop out of the profession (Bureau of Labour Market Research 1985:1x; Lewis, Harris and Cox 2000:6-7; Roberts and Ayre 2001). Women at all ages leave the profession at a steady rate, while men are more likely to stay in the profession until retirement (Australian Bureau of Statistics data in Ayre 2001:8).

In 2000 the Women in Engineering Committee of the Institution of Engineers, Australia (IE Aust) instituted a research project entitled the Careers Review of Engineering Women (CREW). The outcomes of the project have been reported by Roberts and Ayre (2001). The project involved a nation wide survey of all of the female members of the IEAust (along with a matched sub sample of male members) with 767 female engineers (42.2%) responding to the initial survey. This led to the establishment of a database with an array of quantitative data identifying where the women were working, the period of employment, type of engineering work, salaries, workplace satisfaction levels and years since graduation. All of these indices were compared with those from the male engineer respondents. The database showed that women engineers are significantly more dissatisfied than their male counterparts with the prevailing conditions and attitudes in their workplaces. Women identify negative perceptions of their suitability, and lack of equitable staff development, promotion, communications and rates of pay as critical to their frustrations (Roberts and Ayre 2001:5). In addition, 36% of the female respondents reported that they had experienced discrimination on the basis of gender. This evidence suggests that workplace culture is significant to women's participation in engineering.

The quality of these experiences, the ways in which workplace conditions impact on life choices, the effects of size of an employer and 'critical mass' in terms of numbers of female professionals are unavailable from the figures alone. There is a need for more qualitative data if the research is to lead to a developed understanding of workplace culture and, more pointedly, to the reasons behind the high female attrition rate. This paper reports on a subsequent project that has adopted a qualitative approach in which female and male engineers were interviewed about their work experiences.

Previous approaches

Traditional approaches to equal employment opportunity (EEO) policies targets women as the source of the problem, identifying their apparent unwillingness to make non-traditional choices, or because their domestic obligations mean they require 'special assistance'. (Bacchi 1999). EEO initiatives have clearly benefited women and other marginalised groups, but, as Bacchi observes, their beneficial effects come at the cost of requiring conformity to existing norms of workplace behaviour.

With regard to engineering, such approaches focus on its failure to attract women at secondary school level (Bureau of Labour Market Research 1985:15; Jawitz, Case and Tshabalala 2000), the need to improve women's confidence and success in preparing for engineering courses or engineering professional practice (Ayre and Beynon 1988; Maskell-Pretz 1997:34) and the influence of women's childhood socialisation on their acquisition of technical skills (Hacker 149-50:1989; McIlwee and Robinson 1992). Much of the relevant literature emphasises attitudinal barriers that operate beyond the workplace and which prevent women from gaining entry to, and succeeding within engineering (Bielski 1989; Bureau of Labour Market Research 1985:15; Maskell-Pretz and Hopkins 1997). Women are sometimes assumed to lack expertise, confidence and significant exposure to technology (see for example Cockburn and Ormrod 1993; McIlwee and Robinson 1992). Yet, women engineers who participated in the interviews in this study often expressed a childhood fascination for, and an expert facility with, engineering technologies. Other researchers have highlighted women's contributions to technological developments throughout history (Clarson 2000; Oldenziel 1999; Stepulevage 2001). These authors suggest that the view that women are technologically lacking is itself a contested product of gendered struggles over the meaning of technology; struggles in which women have been historically less successful in their claims than men. In short, it is not that men are 'objectively' more technically minded, but that the work that men do, and masculinity itself, is read through a cultural lens that invests them with 'technological' significance. Engineering, as an occupation strongly associated with technology, is then gendered as masculine.

Those explanations that focus directly on women in the profession may, unintentionally, support equity and access programs that aim to increase women's entry into engineering by targeting women themselves, without problematising or changing the way engineering is taught and practised (Rosser 1998:175, 177). In these approaches engineering is maintained as value neutral with the implication that, once barriers and discrimination preventing or obstructing women's participation have been removed, they will be free to compete on equal terms with men. This study found that although providing equity programs and alternative support structures will be of benefit, such strategies often receive a hostile reception from many female engineers who view such initiatives as undermining their professional credibility. In addition, this research suggests that women engineers in Australia are often highly critical of an approach that effectively delegates responsibility for change to isolated, and sometimes embattled individuals who are attempting to balance high workloads, family responsibilities, and the personal and professional costs and demands arising from being female in a male-defined culture. Our study argues that change strategies must be directed at the organisational culture in which women engineers are located.

The study

The project commenced in 2002 and involved the conduct of interviews with engineers from regional, remote and metropolitan centres of Victoria, Queensland, South Australia, Western Australia and the Northern Territory. Fifty-one semi-structured interviews were conducted with 41 women and 10 men engineers, and a further 4 interviews were completed with women engineers via email. The sample group was drawn from people who had indicated on the original CREW survey that they were willing to participate in follow-up interviews and from additional contacts supplied by various state-based Women in Engineering groups. The sample was generally representative of the spread of Australian women engineers in terms of age, career progression, employment type, geography and engineering field. Those interviewed included civil, structural, electrical, metallurgical, mechanical, aeronautical, chemical, and environmental engineers at a range of ages and career stages in companies, consultancies, and government agencies.

All interviews were conducted by the first author, enabling a consistent approach in the conduct of the interviews and the eliciting of additional information as themes began to develop in participants' responses beyond the basic interview questions. Participants were asked to summarise their work history and current work, along with questions about why they chose to do engineering, what they thought it means to be a "good engineer", whether they ever felt uncomfortable at work, what changes they felt had occurred in the engineering profession, what they would change about their own experience if they could, why they think women engineers are leaving the profession and what changes they would make to facilitate women's career progression in engineering as well as some questions regarding their household and family arrangements and whether that resulted in any conflict or tension with their professional life. The analysis of the interview material focused upon how women engineers negotiate the cultural field, the meanings they bring that both subvert and cooperate with their cultural positioning as women or 'non-engineers', and the effects that these ways of thinking have upon them both personally and professionally, upon the organisations they work within, and upon the effects of engineering work. At the time of writing the analysis of the interviews is incomplete. The following discussion constitutes the major themes emerging from preliminary analysis.

Findings

Fitting in

Far from being uncomfortable with technology and lacking in assertiveness the interviews suggest that a number of women engineers are strongly masculine identified. For instance, the words these women used to describe themselves include: 'bullish', 'stubborn', 'determined', 'technical', 'you have to be tough', 'not the girly type', 'competitive', 'proactive', 'big picture focused', 'managerial'. They were also clear that their survival in engineering was due to them being unlike other women: 'a lot of the females that I meet I would not suggest it for them', 'there's no point getting more women in unless the environment changes, otherwise you're only going to get the odd one or two nutters like me that places a different emphasis'. These women expressed little or no difficulty getting along with men, did not feel discriminated against, were less likely to attribute their negative experiences to gender difference, were happy in the career and planned to stay in it. For these women, having established their technical competence, 'the whole female thing just disappears'.

These women tend to be far less critical of the culture of the engineering workplace, and of management and company objectives, and they assume that the work place culture is value neutral:

> I think anybody adapts to the culture, male or female, I don't think the workplace is biased to males, or that women would leave because they were finding pressure on them or they were being harassed, I think it's purely family decisions.

The point of view is very much that women, some women at least, are as good as men: 'if boys can do it, girls can do it'. Interestingly an insistence upon the lack of gender discrimination was often followed up by stories of negotiating pornography and sexual references to their bodies in the workplace, bosses who expected women to be more emotionally supportive in the workplace than men, clients who were unable to give a woman engineer credibility, university personnel who thought women belonged in the arts faculty, and so on.

Women who fit this pattern saw the main problem faced by women engineers and themselves as related to parenting, that is, that the engineering profession is not conducive to having children. This constituted the primary area of contradiction for their positioning of themselves as 'engineers'. The second area of identification with 'women' saw them positing women leaving the profession as a sign of women's advantage. They thought that women left the profession because 'women have all those other touchy, feely skills, communication skills and the opportunity to go up ladders and move the career forward might lie outside of engineering'.

Feminine identified

A second, larger, group of women engineers were more feminine identified. Their values were often expressed in opposition to the main engineering culture, and this group was much more likely to move out of the profession. This group were more likely to emphasise the need for business ethics, environmental values, making a contribution to society, and the importance of feeling aligned with company values. This group also expressed a greater awareness of being treated differently, and this led to a greater sense of discomfort:

> I guess probably where I get discomfort from is the fact that they do treat you as a female, you are a female and they go out of their way to make sure that there's no swearing, they open doors, and it's quite nice, but it makes you aware that you're different, they're doing something, they're forcing themselves to do something that's out of the norm, they're treating you like you're the daughter or the wife, it highlights that you're definitely something different and not something that's normally encountered.

This group sometimes explained women leaving the profession in terms of boredom, or that women are more 'adventurous' and 'enjoy change'. They also emphasised the important role that the support they received in their work group, especially from other women, played in their sense of satisfaction. These young women expressed feelings of discomfort in an all male environment: 'the stares are quite discomforting'. They cited discrimination, preferential treatment toward men, and sexual harassment.

A lot of these women appear to be in grave danger of moving into the third major group identified in the interviews. In this group, for both men and women a sense of difference, alienation and desire for change becomes more clearly defined. These engineers become increasingly critical of the work environment, refuse to adapt, and end by leaving the profession.

Resisting the dominant norm

Of the men and women interviewed who had left engineering, most were clear that their decision to leave was not related to their level of interest or enjoyment in engineering work. Instead they pointed to the masculine work styles around them, their refusal or inability to conform to these, or the long-term exhaustion and sense of pointlessness that flowed from the effort expended. These engineers had highly developed critical perspectives regarding the work culture around them, which they saw as different from their own style in a variety of ways. They were also much more likely to be critical of the standard of work being performed around them, and the tendency for men to 'talk up' their work, and their abilities. The women in this group were not prepared to adopt either a masculine or a daughterly position, showed significant self-confidence in their own viewpoints and abilities, refused to accept a subordinate positioning at work, and attempted to introduce their own style into the engineering culture.

Some reported being openly punished for their refusal to adopt a more masculine work style:

> I don't fit in with the staff very well, and basically I'm new and different and they don't want me there.

Although they were happy with her work performance, this woman was actively encouraged by her bosses to adopt a more conformist behaviour style: 'harmonious is what they like, but basically you have to do what they say'. This involved getting 'a space between you and that feeling', and 'putting up a shield against negativity and rejection' in order to 'not upset people', because it makes 'some men feel uncomfortable'.

Both men and women engineers in this group had criticisms related to, or were prepared to enter into conflict with others with regard to: a concern with the 'good of the community'; 'a sensible spending of money'; long term solutions; a lack of respect for the company, other workers, and women; and business ethics, expressed in terms of the obligations of managers to be truthful with clients about the company's performance.

One man expressed a concern with 'conservatism' in engineering, which he saw as 'a little bit dangerous and regressive because it doesn't allow individuality'. This man also saw the lack of company ethics as not only central to his own decision to leave the profession, but also of many women who are less concerned with being a breadwinner and projecting a confident aura:

> If all you get out of your workers is your money and a little bit of satisfaction out of the authority type power stuff then you can do that as a bloke engineer, you can get along alright, if you want any sort of equity, justice and ethical issues to be predominant, then engineering's going to be a difficult profession. …. We are now so much more aware of stuff, we know how much damage we're doing to the planet, we know what the impacts are, but the inertia, particularly in the engineering profession, makes it very hard to make the changes and do the things that most people know that they could do.

These engineers pointed to pressure and exhaustion from bearing the burden of bringing about change in the profession:

> I think people just don't stay in because you reach this point and you just realize that it's just not worth it, you stop hitting your head against the brick wall, it doesn't hurt anymore and you just realise that there's a point where there's, there are other things to do and you can do that. … I guess when you're young, I guess it's happened you know, every generation as a female you think you can make a difference, you can make a change, you want to get in there and change people's attitudes and do all that thing, but you reach a point where you're saying I think I've done my bit perhaps, I don't think it needs to be me anymore, you've done what you can do with the resources that you've got, I reach a point where I'm not prepared to put anymore of myself into it you know.

One woman also felt that her refusal to play down her femininity was a direct cause of the extreme sexual harassment that she experienced at work.

Discomfort in the workplace

When asked about discomfort experienced in the workplace, men's responses were quite different from women's. Men most often cited a particular example of a difficult working relationship, where women referred to gender specific difficulties. Only four of the 23 interviews analysed at the time of writing said they felt no general discomfort, or gender related issues at work, (although one also spoke about problems getting more junior men to accept her authority). The most commonly cited source of discomfort for the remaining group related to the 'boys club'. This included being overlooked for promotion and opportunities; being seen as about to 'go off to have babies' and 'not management material'; and preferential treatment of male engineers. The second most commonly cited form of discomfort for women was problems with more junior men not accepting women managers; followed by sexual harassment; pornography; and sexist, and homophobic 'jokes'. Least commonly cited forms of discomfort among women were competition from other women; clients not accepting women as engineers; being excluded from workgroup social occasions; lack of family friendly work culture; and problems with women administrators. Interestingly, while the lack of family friendly policies are often cited as the main reasons women leave the profession, this was not a common cause of discomfort in the workplace. In fact women who had left, or who were thinking of leaving, did not emphasise the lack of family friendly work cultures in their own experiences.

What is overwhelmingly evident in the interviews in general is that women engineers do not complain directly about sexism, or the behaviour of the men around them. There was a tension in the interviews between on the one hand reports of difficulties and dissatisfaction, and on the other frequent claims that ‘in general there’s no problem’. There were also a number of comments suggesting that equality means sameness with men. To be taken as similar to men is a relief in a culture that will not tolerate or respect difference.

> In a lot of respects the fact that they’ve forgotten that you’re even there or that you are different is a positive sign I think as well in that you’re just being treated exactly the same as they would treat anybody else you know, so there’s very few times that you feel standing out.

This kind of commentary provides clear evidence of the masculine gender of the profession. Women manage their behaviour in order to ‘fit in’, to avoid being noticed or attracting negative attention.

> I know I shouldn’t make a big, I don’t like to make a big issue of this because I did generally get on with the males, but you could never blend into the background, you were always the focus, like they were always waiting for you to stuff up because that was just fantastic … because they can give them a hard time, I mean you know what guys are like when they’re together.

While the lack of workplace provisions for parents and overwork is clearly a problem that contributes to women leaving the profession, the problem is more complex than this. Although women’s interviews were littered with examples of cultural pressure upon them as females, few explained ‘women’s’ decisions to leave the profession in terms of their ‘outsider’ status. Most women and men continued to ‘not notice’ this pressure to use Tonso’s (2001) words, a practice which only serves to reproduce women’s status as aliens.

Results and conclusions

One of the most critical preliminary conclusions of the study is that the engineering workplace is intolerant of values and behaviours that diverge from dominant norms. Responses indicated that women engineers do not leave the engineering profession as a result of family responsibilities, or their lack of confidence, technical expertise, or interest in engineering work compared to men. While women were far more likely to refer to the lack of a family friendly environment within engineering workplaces, a more significant contributor to their reasons for leaving the profession was a feeling of alienation within the prevailing workplace culture. The engineers who had left or indicated they were thinking of leaving the profession also tended to complain about competitive work relationships, and the lack of emphasis upon business ethics, environmental sustainability, and the social implications of engineering projects. They were also more likely to express a strong desire for more innovative approaches to engineering work. Women engineers who refused to adopt masculine patterns of behaviour were also more likely to leave the profession than those who conformed to prevailing styles of behaviour.

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Acknowledgements

The authors would like to acknowledge the funding sources for the project, namely a collaborative research grant of $35,000 from the University of South Australia and a travel grant of $10,000 from the National Women in Engineering Committee of the Institution of Engineers.

Perceptions of engineering from female secondary college students in regional Victoria

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Abstract: *Survey and focus group interviews with female students in regional Victoria resulted in identification of four perceived barriers that influence them to exclude engineering as a career choice. These barriers were identified as a lack of interest in the perceived image, a lack of knowledge, a traditionally male-dominated industry, and limited recognisable role models. This paper reports on what Year 10 females are saying about the barriers and, consequently, how engineering can be promoted to overcome these barriers.*

Keywords: *women in engineering, perceptions of engineers, promoting engineering, regional universities*

Introduction

Engineering has long been perceived as a gendre-segregated industry (Cobbin, 1993), a perception that is supported by Australian Bureau of Statistics figures which puts women's participation at approximately 10% of the workforce. In this context it is pertinent to consider the perceptions of females (ages14-15 years) and assess the impact of these perceptions and the resultant limitations in career choice.

In the context of addressing the imbalance we need to look beyond the legislative framework and recognise that diversity in the workforce has tangible benefits. A good company image that incorporates the notion of a good corporate citizen requires the adoption of society's paradigms of equity and the inclusion of society's full intellectual potential and intellectual resources. A workforce dominantly composed of white Anglo-Saxon males tends to produce similar outcomes and may limit the problem solving ability of a group. Diversity in racial, ethnic and gender groups is likely to produce diversity of thought and better problem solving capacity (cf. Institute of Engineers, Australia, 1996).

There is international concern about current and projected skills shortages in the engineering sector. Recent studies have identified skills shortages in professional engineering disciplines in regional Victoria (McKenzie, 2002). The University of Ballarat is a dual-sector institution in western Victoria that aims to serve its regional community. It is the third oldest tertiary institution in Australia, dating back to the formation of the Ballarat School of Mines in 1870, and has taught a range of engineering disciplines since that time.

Currently, engineering degree programs have less than 2% female students and will this year graduate no female engineers. While female students (both school leavers and mature entry) are normally a minority in engineering disciplines in most Universities, it has been identified that the University of Ballarat is significantly below the percentages in engineering disciplines in other Australian Universities. A project funded by the University's Equity Grant scheme was initiated to investigate the perceptions of engineering within female secondary college students (Year 10) in western Victoria. The outcome of the study should help focus future efforts to improve recruitment of female students to engineering courses and provide some indication on the impact of promotional activities, including those being undertaken by the University.

Promotional activities, supported by funding through the Victorian Government Science in Schools program, include the development of hands-on robotics classroom sessions with year 5 to Year 10 students at six schools in the Ballarat area. This program to date has involved nine teachers, ten classes and around 260 students. In addition, a growing activity in support of VCE Physics Unit 4 involves a civil engineering academic running workshops with demonstrations of concrete beam failure to over 20 schools in western Victoria. Finally, for the first time in 2003, targeted scholarships to female applicants have been offered.

This paper reports on some preliminary trends that emerged during discussions with the females focusing on their perceptions of the barriers that prevent females from choosing engineering as a career and how these barriers could be broken down.

The Methodology

This research uses qualitative research methods to gather primary data from selected participants. Such methods were preferred over quantitative approaches as they provide latitude for exploration and construction of social phenomena through an inductive process (Minichiello et al., 1995). Surveys are used as part of the participant selection process; however, the primary means of data gathering is semi-structured focus group interviewing in an attempt to access and explore females' constructions of engineers and the factors that may contribute to development of these constructions. Focus groups are used rather than individual students so as to provide a less threatening environment for students. Discussions in focus groups provide opportunities for the members to prompt each other's thought processes so that differing perspectives can come into contact (Maykut & Morehouse, 1994).

School and participants selection

Selection of schools was mostly based on student entry into the courses at the University of Ballarat for the past ten years. Eight schools agreed to participate in the study from western Victoria. The schools are classified according to the following school types to assist with theoretical sampling methods: Government Multi-campus (School B, School D); Government single-campus (School C, School E); Rural (School G); Independent (School J); Catholic

Females (School I); Catholic Co-educational (School F). Two additional schools were asked to participate but have not continued through the project.

The study targets females in Year 10 (aged 14-15 year olds) as anecdotal evidence suggests that students at this level are beginning to form ideas about career options in terms of what is realistic and academically achievable.

There were two stages involved in participant selection. The first involved gaining student consent and determining the initial sample size for each school. Nearly all Year 10 females from the schools were asked to participate in the study. The school distributed the letters, plain language statements and informed consent forms for the student and their parent/guardians. Return of both student and parent/guardian consent forms were required for the student to participate in the study. It was expected that between 160 and 180 students would provide informed consent from a total population size of about 669 year ten females at the eight schools (ie. 24%-27% participation).

The second stage in participant selection involved choosing students to form the cohort for the focus group interviews. Consenting students were asked to complete a "Career Orientation Survey" (Appendix 1) designed to indicate those students who may be open to a career in the engineering sector or similar areas. The surveys were distributed and collected by the contact teachers. Theoretical sampling (Minichiello, et al., 1995; Merriam, 1988) provided a means of selecting students on the basis of the survey results. The levels of the sampling strategy are outlined in Table 1.

LEVEL	Description
Level 1	Year 10 females
Level 2	School type (6 types)
Level 3	Student likely to choose maths/science in VCE
Level 4	Amount of thought student has given to choosing career (yes a lot, yes some)
Level 5	Whether the student is set in their career choice (no, sort of, yes)
Level 6	Type of career options mentioned

Table 1. Sampling theory for selecting students for cohort for focus group interviews. Acceptable responses are identified in parentheses. (VCE: Victorian Certificate of Education)

Focus groups were formed within schools based on information provided in the surveys. Exclusion of students was based on their lack of intention to do maths/science subjects in VCE (Level 3) and the degree of thought given to their career choice (Level 4). Information at Levels 4, 5 and 6 determined the selection of students into focus groups. The groups were predominantly homogenous groups in terms of stage of career determination (Level 4), certainty in career choice (Level 5) and the type of intended career (Level 6). Where there were by necessity lower numbers of students participating at a school, the groups were less homogenous. For larger sample sizes, the responses of surveys could be grouped at Level 4, then sub-grouped into Level 5, then three students with similar career choices could be chosen at Level 6. For example, a focus group may contain students that had given a lot of thought to choosing a career, had definitely chosen a career, and whose career choices were similar, such as all science related. In summary, the study focuses on those students who are expected to be reasonable to high academic achievers, and have a preference for science and engineering related careers.

Focus-group interviews and analytical framework

The final cohort of students consisted of 58 females. Three or four focus-group interviews of predominantly 2-3 females of 40min to 1 ½ hr in length were conducted at each school. The study will comprises about 31 interviews. All interviews have been conducted by the principal researcher to ensure consistency. At the beginning of the interviews students were briefed on the nature of focus-group interviews (privacy issues and shared input) and the four guiding questions designed to direct the focus of the interviews:

1. What are your perceptions of engineers and engineering as a profession?
2. Have you considered or would you consider engineering as a career for yourself?
3. What are your perceptions of the University of Ballarat as an option for your tertiary education, especially in the area of engineering?
4. What has influenced the development of these images of engineers and the engineering profession, engineering at the University of Ballarat, and your choice in career?

Students were first asked to draw a poster of an engineer doing what engineers do in an appropriate environment, name the engineer and describe their work. This gave students a chance to think about their own images without being influenced by the group. It also acted as a reference point for later discussions. All interviews progressed using an interview schedule that followed the four guiding questions, however, the "flavour" of each interview was unique, depending on the depth and type of information profited and the degree of probing used by the interviewer.

The purpose of this study is not to generalise within the variety of student "types" (such as, drawing on types of career orientation) or school types (such as females catholic and co-ed catholic), but to gain insight into the variety of ideas that year 10 females have about engineers and engineering.

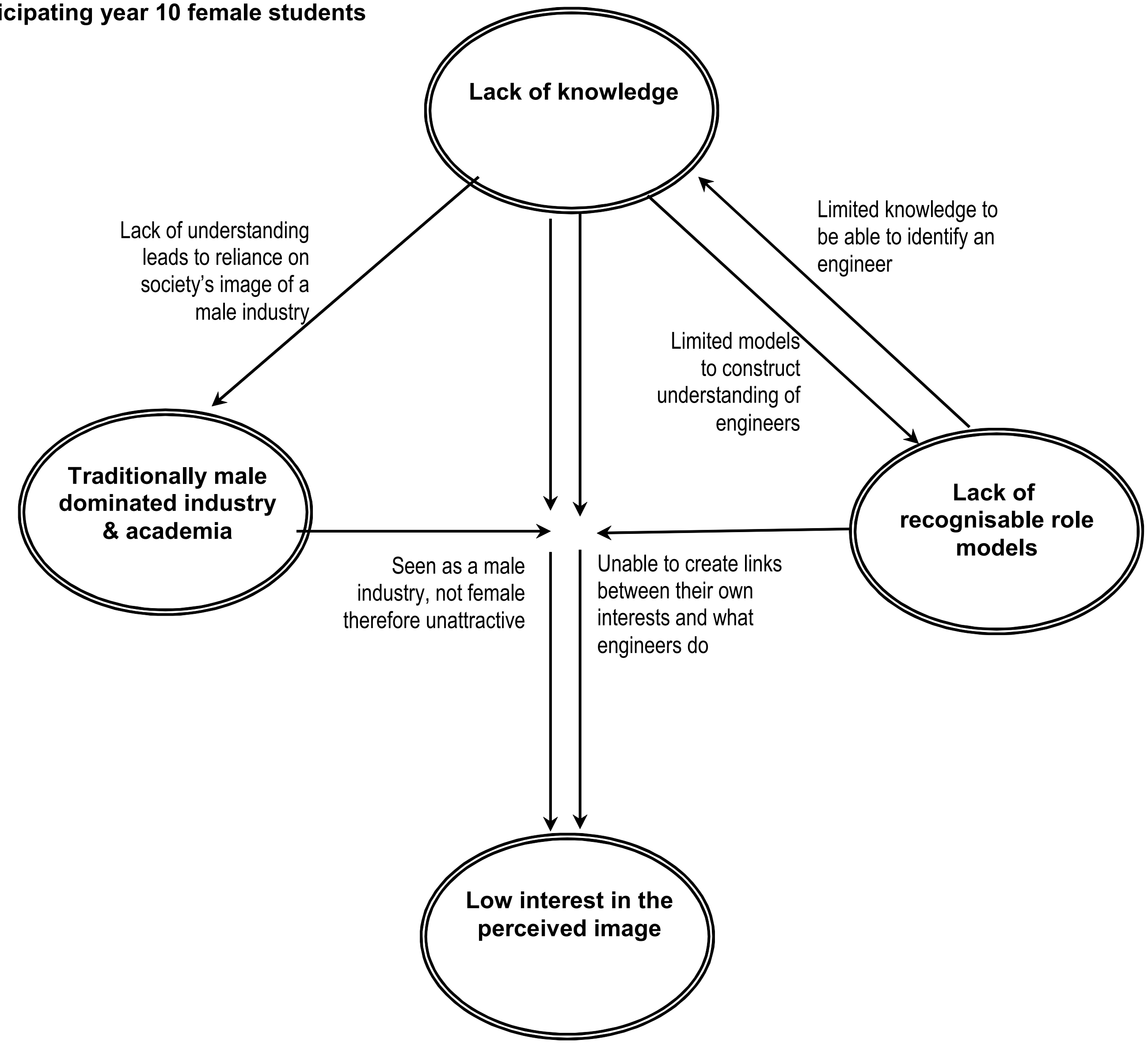
Some preliminary trends in thinking about barriers for engineering for females

Through analysis of the data it became clear that some participants were recognising barriers preventing females from choosing a career in engineering. Having discussed these barriers, some females suggested ways in which engineering could be promoted to make engineering more attractive or accessible for females.

The ideas presented here relate to the unaltered images, both accurate and inaccurate, that students captured in the poster images of engineers, because it is those images that students are probably using to make career choices at this stage.

In presenting the barriers that female students raise, the following section begins by describing what appears to be an overarching barrier, within which other barriers reside. Each of the subsumed barriers will then be looked at more closely. Diagram 1 captures some of the relationships between four barriers identified.

Diagram 1. Relationships between barriers to girls choosing engineering as a career as identified by participating year 10 female students



Identifying barriers for females choosing engineering - an overarching theme of interest

Common to all students was the conviction that career choices should be based on what the individual "enjoys", for example, something that they are passionate about and gives them a sense of achievement. Such enjoyment emanates from their interests, and it is through the interests that students classify certain activities or qualities associated with a career as "attractive", "appealing", "relatable," or conversely, "unattractive", "boring". The following student identifies how recognition of interests appears to be fundamental for career orientation:

> "[I]f you're interested in something you're going to try to find what it is you can do. If you're not interested, then you're not going to say 'Oh, I'll go and look it up anyway!'" [I2]

This guidepost of interest is a fundamental barrier to females choosing engineering that appeared through the interviews. The other three barriers appear to be subsets of the student interest, perhaps contributors to the *interest barrier,* ie. a lack of interest in the perceived image of engineers and the industry.

In terms of students developing interests in engineering, the problem arises when the majority of females have a limited knowledge and understanding of the industry and its practitioners, presented here as the *knowledge barrier*, such that there appears to be a tendency to rely on the traditional male-dominated image associated with the sector. This is emulated in the following response from one female:

> "[W]hat I know about it or think I know about it, I don't really like working with metal and technology and electronics and those sort of subjects. They're sort of boring and not really me. I like sort of more food…Cos when you think about it they're sort of boyish, even though females do do it, I don't picture females doing it…" [F1]

Apart from the overwhelming lack of identification with her perceived image of the engineer, the maleness and exclusivity of the types of work and the materials they work with is evident in this student's response. This traditional male-dominated image of the engineer and the engineering industry has been recognised as a *male-dominance barrier* to females entering engineering. The perceived image of the engineer and "his" work is unattractive for her, and a career in this type of activity is passed off as male.

Drawing further on an apparent lack of knowledge in the minds of some females, an inability to "relate" their interests to an engineer due to this lack of knowledge is also a result of the failure to recognise the presence of the engineer within society:

> "[I] I knew more about an engineer and what they did I'd relate more to what I like to do. But because I haven't heard anything on TV or seen anything in newspapers, it just doesn't appeal to me because I just don't know anything about it." [F1]

This leads to the *recognisable role model barrier* of there being a perceived lack of recognisable role models being projected to these females, a perception echoed by Jacobs and Scanlon (2002).
Although the above mentioned barriers appear to be intrinsically linked in the minds of these females, a closer examination of how the girls have portrayed them as a barrier can assist in giving direction in breaking down the barriers and promoting engineering for women.

How lack of knowledge excludes engineering from career choice

Many of the females had a limited awareness of some aspects of engineering. This became evident through some of the narrow portrayals of engineers on the posters and during the proceeding discussion. Commonly, the females were aware of one or two kinds of engineering that they had been exposed to, such as an aeronautical engineer, the construction engineer, the engineer who sits at a desk and designs things, the engineer who works in an environment surrounded by oily machines. Areas that some females have limited knowledge in include: the variety of types of engineering, what engineers do, the types of environment they may work in, what they may be working with, and the types of social interaction that they expect the engineer to be involved in.

Some students perceive such limited understanding as resulting from the information not being made available to them. It appears that some consider dissemination of information to students as predominantly a responsibility of their school and universities, as typified by these responses:

> "We don't really get told about engineering at all at school. You don't hear much about it all. I think there needs to be more said about it, explained what it is more." [F2]
>
> "Universities should give year 10 or 11 females a go…explain it more, show them what's involved because I don't really know what it involves." [J2]

Whereas, for others, knowing an engineer helps them to build an understanding:

> "[Y]ou don't learn much about what an engineer does…I don't know anybody who's an engineer so [I] can't find out about what they do, or if they like their job" [J3]

Some females acknowledge that having limited knowledge presents itself as a barrier for them when choosing engineering as a career as they are not informed of what engineering offers when making decisions about careers:

> "[I would probably consider engineering for myself] if I learnt a bit more about it and did a lot of research about it." [I4]

A female who has decided that she wants to be an engineer exemplifies this. Having siblings who are engineers and doing work experience at an engineering company helped to construct her knowledge and understanding of the engineering industry: "[I want to be an engineer] because I've seen what they've done and I think 'That could be fun, maybe I will do that.'" These perceptions are also reported in the study by Beder (1999).

Breaking down the knowledge barrier:

Analysis of the variety of responses identifies that participants appear to be addressing their lack of knowledge in two ways: thinking about what they want to know and how they want to be able to experience it.

In the first instance, students want to obtain a holistic picture of the engineer and what he or she does:

- "what they make, what they're actually doing" [J3];
- "what their specific job is" [I4];

- “the day to day what happens, do you sit at your desk or do you get out and help do stuff, or do you work on your own or do you work in an office with engineers.” [J3];
- “explain if it’s a satisfactory job. I think give a lot of detail about it. Give lots of information about the course. What job opportunities are available” [F2];
- “the different branches they can go off into…” [F3]

The ways that this knowledge could be experienced relates to making it available in their own environment (within school) or moving into what could be considered the world of the engineer:

- “Schools would be the best place” [I4]
- “Just need to have some experience of it, maybe put I into our curriculum…” [J3]
- “Something in school, designing like a model” [J3]

and

- “Tell you and show you what they actually do with the different types” [I4]
- “You could do an excursion…put it in [females’] heads what [engineers] do” [J3]

A closer look at the lack of recognisable role models

> “I don’t really know what any of the engineers do. I don’t know if these images [that we’ve drawn] are crap. There’s nothing that advertises it, nobody talks about it… But with engineering there’s like nothing that would advertise it. And then when you get the images, the only ones around you saying they want to be an engineer are guys, so you just get an image in your head that it’s a guy thing.” [F1]

The above response suggests the perceptions that engineers tend to be “behind the scenes,” and are not widely advertised or represented in the media. As a barrier to females choosing engineering, without the awareness of it, decision making about career orientation fails to include engineering as a potential interest, as exemplified by the following response:

> “If I knew what one is, I might know [if I knew someone who was an engineer]. See I probably do know someone but I don’t know what it is.” [F1]

It became evident during the discussions that the females construct their image of the engineer from their life experiences, especially through personal contact with engineers or people that share with them in some way what engineers are and do. Such people included parents, relatives who have been engineers, teachers, such as a science teacher who equated the current topic of physics to engineering, and resources available from school, including careers booklets or Internet searches for careers information.

The media appears to have played an important role in educating students and providing a recognisable image of the engineer. One student mentioned a movie with an engineer that builds models. As this is the only exposure she has had to engineers, her poster reflects the processes and activities that she saw the engineer involved in, namely designing and constructing models for buildings.

Breaking down the recognition barrier:

Not having a recognisable image or role model appears to often leave the females with a limited knowledge. Conversely, without the knowledge to be able to recognise what an engineer is, evidence of engineers and engineering activities remain unnoticed, as expressed by this student.

"If they hear people talk and say that it's a good thing and make people think about it cos otherwise they don't think about it, because otherwise they don't recognise it that much." [F1] Commonly, students suggested raising an awareness of the role and image of the engineer so as to promote a consciousness of their presence in society. Consequently, education aimed at increasing the awareness of engineering should provide both information about them and offer role models that are prominent in the community.

A closer look at the image of a male industry

Of all posters, 23 posters represented male images, with nine female images. Four of those participants who represented female images were related to a female engineer. Another two participants said that initially they would have drawn a male but were influenced by the rationale for this research. The opinion of many can be captured as: "Engineers just sound manly" [I4] and "I think it's a guy thing" [I4].

Students appear to be recognising two influences dominating their perspective on how gender typing relates to career orientation. The first influence is the societal influence: "It's just a social thing. Its got nothing to do with ability" [I2]. Within this view males and females are considered equal, and it is more the societal pressure that influences females' tendency to remove engineering from their choices. For a number of females, interest transcends societal pressure: "If you think it's male-dominated then it becomes that in your mind… If I really wanted to do it, I'd do it. I wouldn't let that stop me." [I3] With this mindset, engineering becomes accessible for females as the construction of gender bias is removed from the equation.

The other influence is the recognition of the differences between males and females: many females equated males with the image of engineers more readily than females because "[i]t's sort of an innate ability for guys, with the whole engineering side, they know what it is, they've been playing around it for as long as they could walk with dad and pa." [F3] The phenomena of the "guy thing" and "girl thing" evolves from this difference, and presents itself as a barrier due to a lack of females being able to identify with the male engineer. For one female whose perception of engineering is centred on building design and construction, designing may be common for both genders, but it is the materials that are being worked that differentiates: "Most females that are designers they design clothes rather than buildings cos buildings are sort of a guy thing…guys like big things and tractors and big construction things. They're like, 'I want to design that.' It's not such a female thing." [J3]

Breaking down the barrier:

Changing the male-dominated image as perceived by these females, either as a product of social construction or as the innate characteristic, requires presenting the industry as not just for men and "not a sexist thing" [J4]. This deals predominantly with putting women into the engineering role: "you'd need to see actual women on the job" [F1]. A number of suggestions were made as to how the images presented to females could include the female image. For example, posters depicting women doing the variety of roles, and males and females working together targeting the idea that females can do the work and that there is a level if collaboration and harmony within the work environment. The value of projecting a "unisex" [J4] environment, a student recognizes, is that "females might feel more comfortable in that environment" [J4]. One female warns that efforts to make engineering more attractive for females should not present an unrealistic image for females: "if I was looking at it I wouldn't want it as female engineering, you'd want it to be engineering the same as male…you'd want to say it's not just males who can do engineering, females are just as good" [J4]. Personal contact with female role models from the engineering industry were also considered important, such as females talking to students at schools, females taking on presenting roles during school visits, and at University Open days, career days and during university visits. A woman engineer talking to females only was suggested in one interview so as to allow the female voice to be heard and not muffled by the male voice. The value of getting this female face of the industry is that they can "get a woman's point of view" [F3], get a taste of "whether they enjoy it" [F1] and there is an opportunity to hear how it actually is for females.

Conclusion

This on-going research project has identified similar issues to other recent researchers and provides support for the needs of a number of regional, national and international initiatives to promote engineering. For these year 10 females the real barriers to women choosing to study engineering at University are substantial and go well beyond the image of the profession. They encompass a lack of interest in the perceived image of engineers and the profession, misunderstandings about the nature of the work, lack of exposure to professionals and the negative perceptions of a male dominated industry.

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Students perceptions of gendered language in an engineering classroom

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Abstract: *The importance of language both in written and oral form has been underestimated in engineering education. Observation of an engineering classroom environment identified persistent use of comments with sexual connotations and examples of sexist language both in terms of treating women as objects as well as excluding them from the technological world.*
In a study conducted into the dynamics between genders in an engineering classroom in an Australian University, language was identified as a significant aspect of the creating of a gendered environment. The students in this study generally indicated that they were not concerned at all about the use of bias language in the classroom nor to its affect on them or others. However, the questions and discussion on language created the strongest reactions from both sexes in relation to the whole discussion on possible gender differences in the engineering classroom. This study highlights the importance and power of language and the need to understand its use and affect. This paper presents part of the results obtained in the study conducted in 2000.

Background

The Importance of Language

Language is a guide to our social reality [Wittengstein, 1961, cited in Wilson, 1992] as it both shapes and reflects the way we think [Wilson, 1992; Pauwels, 1991]. Language, in the wider English speaking community, has created a reality which is gender biased, as it often excludes women and can treat women and men unequally. The assumptions that our language makes tend to be that the male is the 'norm', female is the 'other'. Thus the language we are use to is sexist and therefore is ambiguous and unjust to women and girls. The most familiar example is the use of the generic terms such as 'he' or 'man'.

Although adults know logically that 'he' is to be inclusive, they tend to think of 'he' as meaning male. An example which clearly demonstrates the deliberate exclusion that language can create is reiterated by Miller and Swift: a British Act of Parliament in 1850 gave official sanction to the invented concept of the generic 'he' and the concept was adopted by English-speaking-countries. Yet, on the other hand, this same pronoun 'he' has been used as the justification for excluding females from admission to or membership of institutions whose constitution or bylaws used the generic 'he' to refer to members [Miller and Swift, 1981 pg 33-38].

Language in Engineering

Engineering, as with other professions is not isolated from the language used in the broader community which is accepted and even expected as appropriate social and professional behaviour. However, engineering does have specific language-related issues which have been allowed to develop through the sub-cultures that operate within the engineering profession.

Fiona Wilson in a paper *Language, technology, gender and power* [1992] argues that men seek, 'knowingly or unknowingly, to facilitate the technological change process by drawing upon linguistic resources which reproduce relations of power'. That is, they can maintain dominance by controlling language and thus recreating reality as it evolves in a constantly gender biased way. Examples which illustrated this include the story retold by Miller and Swift [1981] above and Tonso [1996] and Jolly's [1996] findings of women's experience of overt and covert verbal 'put downs' as well as the persistence of sexist and sexual comments in engineering classrooms.

Sally Hacker's [1989] research on engineering education showed how the images of gender were used in the making of an engineer's skill base and in fact went on to claim that the exclusion of women is part of the process of creating these skills and is done in part through language use. Supporting this notion is Tonso's [1996] work which collected evidence in an engineering design classroom of the mild but persistent use of profanity and attention to semi-sexual, double entendres by male students. This male peer behaviour combined with the male engineering lecturer's persistent use of images from military and hunter/warrior traditions, Tonso concluded, created an environment where women's social worth was undermined and established a context where a female student would find it difficult to coexist with the projected engineering professional values. The discourse, therefore, in this design classroom defined the tone of the classroom and reinforced engineering traditions and to a limited extent redefined customs.

On the positive side we should recognize that our language is not fixed but constantly evolving [Pauwels, 1991] and so it is important to have a greater awareness of these expressions and usages. This paper presents the results of a study done into the perceptions students have on language used in an engineering classroom at an Australian University in 2000.

The study

The study on gendered language within an engineering classroom is a section of a much larger study performed to investigate the dynamics in an engineering classroom. To do this both the learning environment and social world of an engineering classroom was studied and the complex interactions between student behaviour, their knowledge, and learning experiences within that classroom was investigated [Burrowes, 2001]. An ethnographic research methodology was used to obtain an understanding of the behaviours and socio-cultural activities and patterns of a group of engineering students, from their perspective, in a 'typical' engineering classroom setting. Ethnographic research is designed to present a dynamic picture of the student group and their interactions and provide an alternative, more humanistic research paradigm to the traditional empirical scientific method.

The process of ethnographic research is essentially to collect descriptive data as the basis for interpretation and analysis of the research questions. Data for this research study was obtained primarily through fieldwork, which involved both observations of the engineering classroom setting and interviews of participants within that setting. Surveys were also used and have provided some quantitative measures to increase the reliability of the results. Thus, three data collection techniques were used: observation, focus groups and surveys to produce the empirical findings.

The classroom used in this study was a second semester first year subject taken by students in the Mechanical, Environment, Surveying and Civil discipline areas. There were 136 students who participated in each of the two surveys conducted at the beginning and end of the semester, 122 male students and 14 female students (10.3%) which reflects the female average participation in engineering classrooms at the University. Three groups of 6 students participated in the focus groups sessions which were held twice during the semester. There were 12 male students and 6 female students in these focus group sessions. The researcher was also a second tutor in one of the large tutorial groups and so was able to make observations during class sessions as well as in assignment work.

Results

Awareness of Gendered Issues

The predominate feeling expressed by the students involved in the study was that the use of gendered language was not an important or relevant issue to consider in their study environment. Yet the questions on language were the ones that stirred the most active responses. In fact, typical comments from students either through the surveys or during the focus group sessions included such statements as: it is *"irrelevant", "not an issue",* we *"don't care"* as well as it *"doesn't bother me, can't understand why it would"*. Female students appeared slightly more aware in the focus groups and during tutorial sessions but were not willing or able to do anything. As one female student stated; *"mostly males are referred to but I don't think this is deliberate or has any bearing on my education or (that of) someone of the opposite sex"* (Female Student) [Burrowes, 2001]. A male student also inferred that the occurrences of gendered language were not intentional with *"as if it matters, as long as they don't go overboard. It's usually just a slip of the tongue"* (Male Student) [ibid].

Despite being careful with the terminology which was used in the survey and in the focus group questions there remained an immediate negative or defensive response to these questions. Comments such as *"give feminism a rest, will you" to "it is not really an issue if you don't let it be one" to "it can't be helped. The majority of classes are made up of males anyway"* illustrate these feelings. Also, *"changing the name of things like manhole cover to say people cover and many other various things, (to try to) equal the different sexes in (the) work place makes me sick, its all just a waste of time"* (Male Student) [ibid].

Awareness of Gendered Language and Examples

The response from the question on how often students noticed the use of male/female specific language or examples in (a) prescribed texts, (b) lectures, (c) tutorials, (d) laboratories, provided an interesting insight into the awareness and/or perception students have of gendered language in their study environment. The results, which are presented in Figure 1 (a) to (d), show that the majority of male students believe that there is never or rarely any male/female specific language or examples in texts, lectures, tutorials or laboratories. There was a consistent group of 12 male students (10%) who did specify that male/female language was used in these contexts.

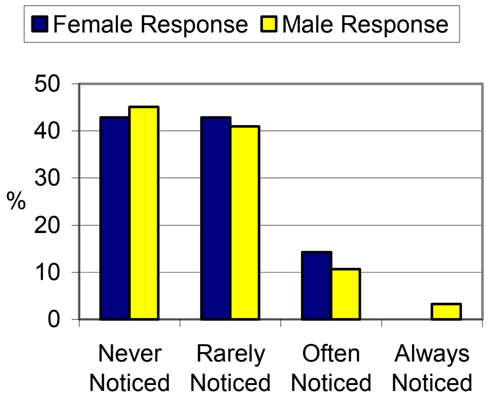

Figure 1(a): Percentage Response to Male/Female Language or Examples Noticed in Textbooks by Gender

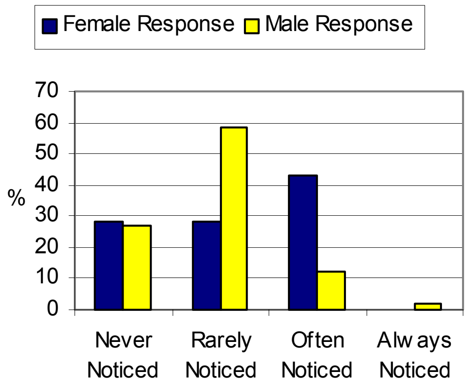

Figure 1(b): Percentage Response to Male/Female Language or Examples Noticed in Lectures by Gender

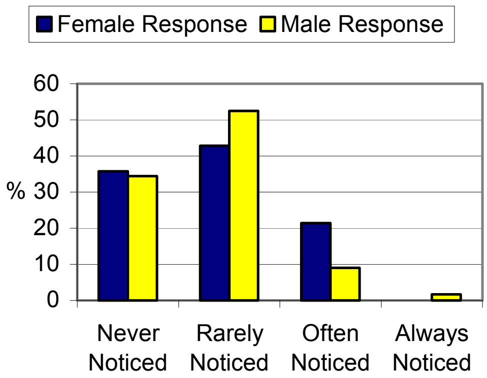

Figure 1(c): Percentage Response to Male/Female Language or Examples Noticed in Tutorials by Gender

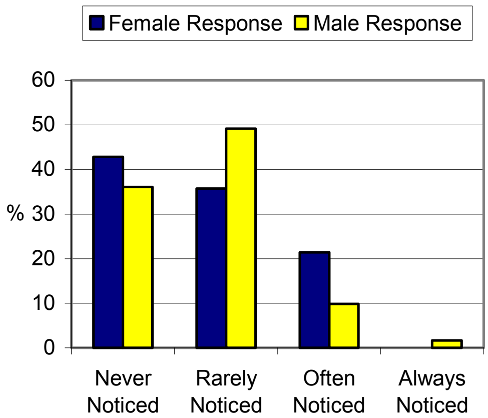

Figure 1(d): Percentage Response to Male/Female Language or Examples Noticed in Laboratories by Gender

Whilst women's responses to this question were also similar in supporting the 'never' or 'rarely' did they find male/female specific language or examples in tutorials, texts or laboratories, there was 44% of the female students who did find that gendered language 'often' occurred during lectures, Figure 1(b).
When asked which gender this language referred to, male student responses were much more divided with 45% saying 'I don't know' and 45% saying it was 'male' with the remaining 10% saying that it was 'female' language/examples. Female student responses were more consistent with 82% saying that the language was 'male' with the other 18% saying 'I don't know' and none of them saying it was female. These results are presented in Figure 2.

Affect of Gendered Language and Examples on Aspects of the Learning Environment
To the question on whether the students in the study felt that they were affected by the use of gendered language, both the male and female student responses showed a strong dismissive attitude. The results illustrated in Figure 3 show that all of the female students said that this (male) language and examples did not make them 'feel uncomfortable' nor did it 'hinder their learning' or 'affect their assessment'. More specifically in terms of making them feel

uncomfortable there were comments such as *'depending on the context'* and *'I merely feel this unfair'* (not uncomfortable).

The male students on the other hand also generally felt that gendered language and examples did not adversely affect their learning with only a small percentage of male students indicating some issues. Four male students selected the 'yes' response to all, which I suspect from later discussions was their way of protesting to the survey.

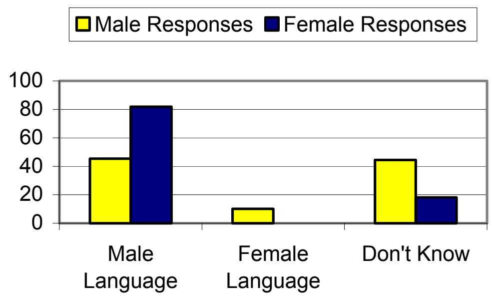

Figure 2: Percentage Responses by Gender to whether Male or Female Language is Used

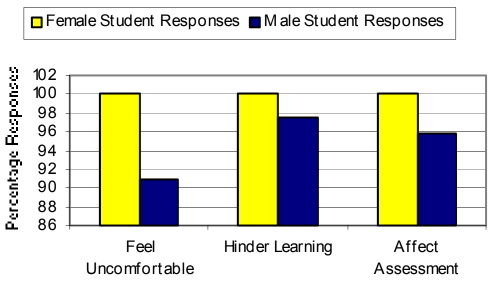

Figure 3: The NO response by Gender of whether the use of male/female language or examples affected aspects of their learning environment

As with other questions asked in the study the initial responses were generally negative and defensive. However, contrary to the above results and some comments made by female students during the tutorial session, 30% responded in the survey to the fact that there was a need to challenge the bias (Figure 4). Also, the comments from female students in the focus group sessions supported the need to challenge the bias, however, most were accepting of the environment. *'I am a female and I don't really see it as an issue, as long as I can understand it I don't care '*(Female Student) [Burrowes, 2001].

On several occasions, female students would make excuses for the male students despite not being happy about it. Comments such as: *"in the context that they are completely unable to understand"* and *"seems to make them feel more acceptable. It gives me the shits"* provides an insight into the deeper feelings of many of the female students. (Female Students) [ibid].

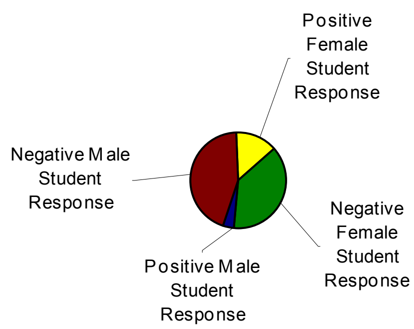

Figure 4: Responses By Gender to Whether They Would Challenge Any Gender Language Bias

One male student commented in the survey "*if I was a female, I would probably challenge the bias, but the language usually assumes male. If it were to assume female most of the time I certainly would challenge it*" (Male Student) [ibid].

During the focus groups sessions there was a genuine feeling from a small percentage of males in the overall group that women did have a difficult time in this area and that they felt most males were not interested or didn't understand or didn't care. A conversation between a male student (MS) and a female student (FS) went as follows.

MS: *"Well I think women add a real separate tone to the group. If there are women present, in a study group or tutorial, they normally set the standard of language"*

FS: *"So it doesn't sink down to the gutter, is that what you are saying?"*

MS: *"Well, yeah. Some blokes can get pretty crude"*

FS: *"And some of the lecturers as well. You can see them stopping themselves before they say something smart because there are females in the audience."*

MS: *"Sometimes it is just a bit of a joke or a bit of play on words but everyone laughs at it. Gee, you could get in a lot of trouble if anyone objected but no one ever has."*

Discussion & Future Work

Women are socialized to gendered language in their broader social context and in non-traditional areas of mathematics and science subjects at school. They have therefore already developed mechanisms to deal with the use of gendered language.

There was a significant amount of acceptance amongst female students that this was 'the way it was' and that they were not willing or able to do anything about it. In general female students felt that they just didn't notice the use of male language and therefore it didn't make them feel uncomfortable. If it did occur they made excuses that it wasn't meant to mean anything. As gendered language is accepted there is no perceived disadvantage and therefore the suspected erosion of their confidence and comfort in the environment is not clearly seen by both genders.

On the other hand, male students were not interested and felt quite threatened by the discussions on gendered language. Generally they would tend to claim that there was no use of gendered language and that they simply could not see any bias. They clearly spoke out if they thought that there was even an attempt to change the status quo and were quick to challenge any changes. Several male students indicated that they felt that it was ridiculous that women should have a problem with male language and would simply put it down to it being an irrelevant issue (irrelevant to them of course). There were a few male students who attempted to evaluate the situation from a female perspective and were also able to sympathise with the difficult situation that the female students have. There seems much potential to work with these positive sentiments.

There is still much work needed to gain a clearer picture of the complexities of language use and affect in the engineering classroom. Understanding of a broader student population as well as the staff perspective needs to continue as our language continues to change. This change then needs to be influenced so that new forms of expression can be developed to describe engineering functions and interactions within engineering in non-discriminatory ways.

Deconstruction techniques have already been presented by researchers to unsettle engineering practice in areas of design [Tonso, 1996] and culture [Copland & Lewis, 1998] to interrupt the fundamental images and assumptions made in engineering that position women (in particular) in the margins of the discourse. The value in this methodology is that it can also begin to build a different way of thinking of language that will be needed to begin a change process towards a genderless classroom.

Conclusion

Language is one of the strongest determinants of the classroom experience for students, yet potentially one of the hardest aspects to address as students in general trivialise it and claim not to recognise it. Students also responded emotionally to the discussion that was generated when gendered language was raised. Yet the continued denial of language use and its power to devalue women is a critical issue for women who are coping subconsciously with the often unintentional questioning of their place in the engineering classroom.

Much of the sexist language which occurs in the engineering classroom, more often than not is not deliberate. Language has been demonstrated to be integral to the practice of power in technological fields, so while the 'male as norm' syndrome continues, there needs to be a conscious questioning of the status of language practices within engineering classrooms instead of excuses.

In changing our language we can challenge any unspoken assumptions and more accurately reflect the reality of the culture and if engineering is to become truly genderless then language will be an aspect that needs special consideration.

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Acknowledgements

This paper is presenting a portion of the study conducted which formed part of my Master of Philosophy Thesis. I would like to thank my supervisors, Prof Catherine Smith & Prof. Adrian Page again for their support in that process.

Challenges in the development of educational programs for MEMS technologies

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Abstract: *This paper outlines the development and continuing process of improvement of the Masters by coursework program in Microelectromechanical Systems (MEMS) at RMIT University. A survey was conducted of recent applicants to establish how applicants came to learn of the MEMS program offered at RMIT University, their previous background, work and industrial experience and the impact of the Masters program on their future career. The results and evaluation of the survey have allowed RMIT University to better focus microtechnology awareness to the appropriate groups and improve the course material and structure of the program to suit the needs of different background students.*

Keywords*: MEMS, education, postgraduate*

Introduction

The CRC for Microtechnology was established by the Federal Government of Australia to provide the vision, infrastructure, skilled people and technologies to enable enterprises in Australia to successfully compete in the international microtechnology industry (CRC for Microtechnology, 2003). As part of this vision, three Australian universities have developed three new microtechnology Masters by coursework programs to increase the skill base and knowledge of microtechnology in professional engineers and scientists. This in itself presents a formidable task for university educators. In particular, the program developed at RMIT was developed to address the educational skills and knowledge necessary for Microelectromechanical systems (Wulf, 2003). Microelectromechanical Systems (MEMS) is a new and rapidly emerging area of microtechnology. Through design and fabrication, MEMS technology combines different disciplines of engineering, physics, chemistry and biology to realise novel miniature devices such as sensors and actuators. The program is designed to introduce students to microsystems technology and to provide the necessary knowledge and skills to design, model, fabricate and interface Microsystems devices.

The Masters by coursework program at RMIT University consists of four courses, four elective courses and a minor thesis project. The four core courses are:

1. Introduction to MEMS: Principles and Design
2. Design and CAD Tools for MEMS
3. Fabrication Processes
4. Materials and Packaging for MEMS

Students are invited to select from a range of elective courses that enable them to specialise in an area of engineering such as telecommunications, optical fibre technology, microwave devices or power systems. The elective courses are intended to allow the student to integrate

MEMS technology into their field of interest. The program through course work, fabrication laboratories, computer design laboratories and research projects teaches students about MEMS technology. An emphasis in the program is placed on industrial and commercial applications of Microsystems technology. The four main objectives of the program are:

1. Design and analysis of MEMS devices and structures.
2. Development of fabrication process and sequences.
3. Integration and packaging of MEMS devices.
4. Characterisation and design verification.

The Masters program has been developed for students to integrate skills and knowledge from different fields of science and engineering. For example, electromechanical coupling of cantilever beams requires students to be able to combine both electrical and mechanical concepts. Students from Electrical Engineering and Mechanical engineering have an immediate aptitude to this program as they are familiar with electro-mechanical and thermo-mechanical interactions concepts.

Three years after the commencement of the program, a survey was conducted to assess the background knowledge and skills of students entering the program and whether, if at all, after studying the Masters program, they would consider changing their career. Further to this, the exposure of students through the media and other sources to microtechnology was surveyed, with the aim of evaluating the methods used to promote the program and technology. In summary, the aim of the survey was to establish the following about applicants:

1. How they found out about the program offered at the University and whether they knew what microtechnology was before they applied.
2. Previous background, work and industrial experience.
3. The impact of the Masters program on their future career.

The survey had a secondary purpose. In this program, students are expected to learn about other fields of science and engineering and be able to integrate ideas from different fields of science and engineering. The results from the survey were used to identify deficiencies in the skills and knowledge of students entering the program. Secondly the survey was used to determine whether the design of the program adequately met the career objectives of the students. These deficiencies were then mapped into the core courses to recognize areas of the program that could be improved or more emphasis placed during lectures and laboratories.

The survey was conducted with 25 applicants in the RMIT Masters by coursework program. The results and evaluation of the survey have allowed RMIT University to increase awareness of microtechnology to different student groups and to improve the course material and structure of the program to suit the needs of different background students.

Core Courses

Microtechnology: Introduction to principles and design

This course is designed to introduce students to the fundamental concepts of Microsystems technology, the concepts of multi-physics problems, MEMS design, MEMS fabrication and MEMS devices and applications. The three main objectives of the course are the design and analysis of MEMS devices and structures, the development of fabrication processes and sequences and to understand the issues of integration in the MEMS context. This course does not assume that students have previously studied mechanics or electrostatics, both of which are necessary to understand the fundamental principles of MEMS design. Some university MEMS programs contain mechanical courses from mechanical engineering degree programs into their postgraduate programs as a bridging course (Lin, 2001). This core course lays the fundamental principles of MEMS and these are expanded in more detail in the three other core courses. The student learns through a series of laboratories about real MEMS devices such as accelerometers and the basic principles from sensor physics and design, the signal generated by the sensor and the processing of the sensor signal. This approach demonstrates the relationship between the sensor design and the system issues. An outline of the course content is as follows:

1. Introduction to Microsystems Technology
2. Microsystems Design and Working Principles
3. Materials, Structures and Mechanical Principles
4. Fabrication and Processing
5. Integration and Packaging
6. Devices and Applications
7. Microsystems: Markets and Future Trends

Fabrication Processes

This course contains an overview of basic semiconductor physics and CMOS device structure and function, provides an overview of the total semiconductor (wafer) manufacturing process, and presents basic descriptions of the unit process modules contained within the fabrication process. The course does not assume the student has education or experience in semiconductor physics, devices, or process technology. It is appropriate for students with minimal education or experience in silicon semiconductor technology.

The course involves CMOS process simulation using IC Fab and SRIM 2000, laboratory fabrication, testing and characterization of silicon gate NMOS or CMOS devices and simple integrated circuits. Emphasis is on the practical aspects of IC fabrication, including silicon wafer cleaning, photolithography, etching, oxidation, diffusion, ion implantation, chemical vapour deposition, physical sputtering and wafer testing.

The course begins with an overview of basic silicon semiconductor physics, PN junctions, CMOS device structure and function, device leakage currents, short channel effects and hot carrier effects. Design and processing techniques that avoid these undesirable effects are identified and discussed. This is followed by a step-by-step pictorial description of process flows ranging from photolithography of starting substrates to finished wafers. The processing details at each step in the process sequences are discussed. Linkages to real world issues in the commercial manufacturing environment are explicitly identified throughout the lectures. Overviews of each unit process module employed in silicon wafer fabrication are presented. Each unit process module begins with an explanation of the theoretical principles underlying the process technology, followed by an examination of how these principles are applied in real manufacturing practice. An outline of the course content is as follows:

1. Photolithography, masking and patterning
   - Light sources and wafer exposure systems
   - Photoresists and their properties
   - Measurement techniques
2. Semiconductor oxidation and diffusion
   - Basic concepts of oxidation

- Manufacturing methods for oxide layer
- Optical and electrical characterisation of oxide layer
- Diffusion process
- Manufacturing and measurements of diffused layer

3. Process integration, testing, bonding and packaging
    - Process integration
    - Device Testing
    - Bonding
    - Device Packaging

Design and CAD Tools

MEMS fabrication processes have serious repercussions on the performance of microtechnology devices and therefore must be considered during design. Most MEMS devices and systems are made of three-dimensional structures that often involve electrostatic/electromagnetic forces, heat transmissions as well as solid/fluid interactions. Because of the inherent complex geometry, loading, and boundary conditions, the finite element method (FEM) is widely used by the MEMS industry for design analysis and simulation of such systems. Facile, integrated and comprehensive software packages are highly desired and now commercially available for MEMS designers.

This course provides the students with an overview of the finite element method, its concepts and its applicability to MEMS. It also deals with process considerations at the design stage. Through laboratory based assignments, and major project work students gain hands-on experience in the use of ANSYS and COVENTORWARE (formally known as MEMCAD) software packages to model and analyse MEMS devices for various practical applications. On completion of this course the student is expected to be proficient in the use of these packages. The main objectives of the course are to develop design concepts for practical applications, model and analyse MEMS devices and structures and to design and simulate fabrication sequences. An outline of the course content is as follows:

1. MEMS Design
2. Systems Approach to MEMS Design
3. Lumped Parameter Modelling: Matlab modelling
4. Fundamentals of Finite Element Modelling
5. ANSYS modelling Techniques
6. Fabrication Layout and Processing Diagrams
7. MEMSCAD modelling Techniques
8. Multi-physics Problems in Microsystems technology

Materials and Packaging for MEMS

Microtechnology is largely based on IC manufacturing to achieve miniaturization and integration. Current materials used in Microsystems devices such as silicon and silicon dioxide have processing and material limitations, inhibiting the development of new devices. As the manufacturing and integration of microtechnology continues to develop, new materials are needed to achieve the performance requirements of sensors and actuators. Existing IC packaging methods are not suitable for many microsystems applications. A package is required to simultaneously allow interaction with the environment and at the same time provide protection from unwanted environmental conditions. This conflicting requirement is driving new research to develop new packaging methods for microsystems applications.

This course provides students with the necessary knowledge and skills for selecting and characterising materials for microsystems applications. This course also provides an introduction to the way in which materials are classified to establish the correct language used to describe materials and their electrical, optical, thermal, magnetic, and semiconductor properties. Other non-standard materials such as polymers, ceramics and nano-materials are covered, with an emphasis on the application of these materials to MEMS devices. The current state of packaging for MEMS is reviewed and the student will engage in a packaging design for a MEMS application. A laboratory component to the course introduces students to material characterisation techniques such as SEM and EDS. The four main objectives of the course are for the student to:

1. To understand the physical and surface properties of materials and how they can be implemented in microsystems applications.
2. To understand the issues of packaging for MEMS devices and the limitations of current packaging techniques.
3. To understand the principles behind several common materials analysis techniques.
4. To be able to identify the most appropriate analysis technique to characterise a property of a material.

An outline of the course content is as follows:

1. Material and their Properties
2. Silicon Compounds and other Materials for MEMS
3. Thin Film Properties
4. Dissipation, Diffusion and Thermal Materials
5. Electronic and Magnetic Materials
6. Polymer Bio Materials
7. Ceramic and Nanomaterials
8. Material Measurement Techniques
9. EDS, SAT, SEM and TEM

Results of the survey

Background and Career

The average age of applicants was 33 years and 92% of the applicants have had on average 5 years of industry experience, with 35% having previous experience in the microelectronics industry and 23% of the applicants working in the microtechnology area. It is clear from the survey that the students of the program are not studying as a continuation from their Bachelors degree. As many of them have already worked in industry, the MEMS program must have an appeal to their future career. This is supported by the fact that 75% of applicants would consider a career change at the completion of studying the Masters program. This is believed to indicate that applicants are willing to change their career focus, and indirectly means that the applicants see MEMS as an emerging technology that will have a commercial impact with an industry ready to support these expectations.

Before the applicants learnt of the program, 88% knew of MEMS and what it means. Figure 1 is a breakdown of the way in which applicants came to learn of MEMS. Most applicants learnt of MEMS through university interactions (lecturers, friends, and laboratory involvement) and the web. As much of the emerging trends of MEMS technology is still confined to universities, this result is not surprsing as university researchers usually disseminate their research and that of others through their colleagues, friends and students.

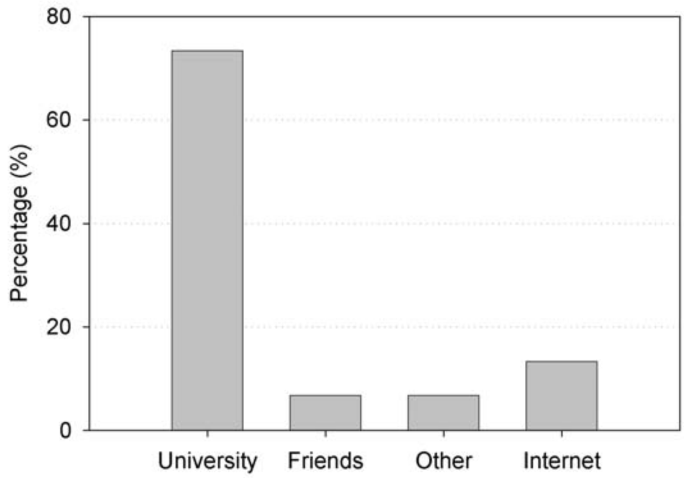

Figure 3: Different ways in which applicants learnt of MEMS, before applying to the program at RMIT

Knowledge and Skills

71% of applicants were familiar with the basic mechanical concepts that are fundamental to MEMS however only 14% had experience using finite element packages such as ANYSY to construct mechanical models. Figure 2 is a summary of the past experience applicants have had with software packages related to the microtechnology field. Clearly Matlab is a widely used and taught software package in Universities. Our approach has been to develop MEMS laboratories using Matlab to explain principles of microtechnology as a stepping stone to more standard design tools such as COVENTORWARE. In the survey, no applicants reported to have used COVENTORWARE or MEMSPro. These packages are becoming standard tools in MEMS design. The low percentage of applicants having used ANYSY and the non-exposure to COVENTORWARE or MEMSPro supports the development of the core course: Design and CAD Tools for MEMS in the Masters program.

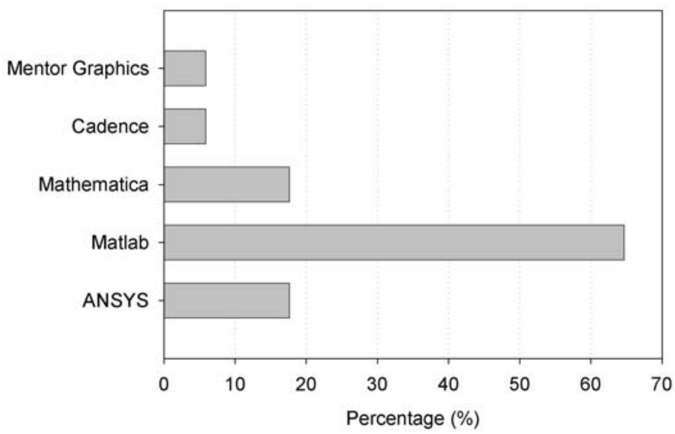

Figure 4: Experience of applicants with analytical and simulation software packages

Applicants were asked about previous science and engineering topics studied during their undergraduate degree. Figure 3 is a summary of applicant responses indicating the percentage of different topic areas studied. Table I is a breakdown of the undergraduate degrees studied by the applicants. 70.6% of applicants are either Electronic or Electrical Engineers, with a small percentage from science and mechanical engineering. This result agrees with the course structuring and student backgrounds of other international programs (Liu, 1997). Most of the applicants had studied circuit theory, magnetics and Electromagnetic Wave Theory (EM Theory) which are core topics in Electrical and Electronic Engineering undergraduate degrees. Applicants have a clear deficiency in electrostatics, with only 1 in 2 having studied the topic, and only 1 in 3 having studied fluidics at an undergraduate level. The same is true for thermal physics. These three topics, fluidics, electrostatics and thermal physics are mandatory to someone learning about MEMS. As a result, the course content that treats these three areas is being expanded and Matlab learning laboratories are being developed for these topics.

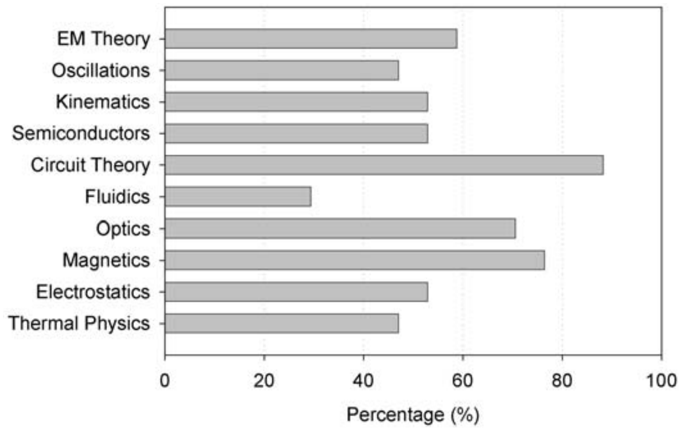

Figure 5: Undergraduate topics studied by applicants

Undergraduate Degree	Percentage (%)
Science	17.6
Electronic/Electrical Engineering	70.6
Mechanical Engineering	11.8

Table 1: Summary of applicant backgrounds

Learning strategies

To a lesser extent, the prefered learning technique of applicants was surveyed. As reported in the previous section, applicants had on average 5 years industry experience and 57% of the applicants were currently employed. This creates an issue for learning delivery strategies for those people who are working full-time and attempting to study part-time. Anecdotal evidence indicates that many applicants withdraw from the program due to work commitments. This issue is further complicated as 71% of applicants prefer face-face lectures. Alternative methods to face-to-face lectures are CD and Internet based learning. 52% of applicants had experience using internet and CD based learning and did not find these methods better than face-to-face lectures. Applicants indicated that Internet and CD based learning was useful for reference only and not as a method for learning. Other education institutions are adopting internet learning as standard tools (Harsanyi et al., 2002). Figure 4 is a plot of the normalised responses of applicants for preferred methods of learning, with 1 being the highest. Hands-on and face-to-face are the preferred methods.

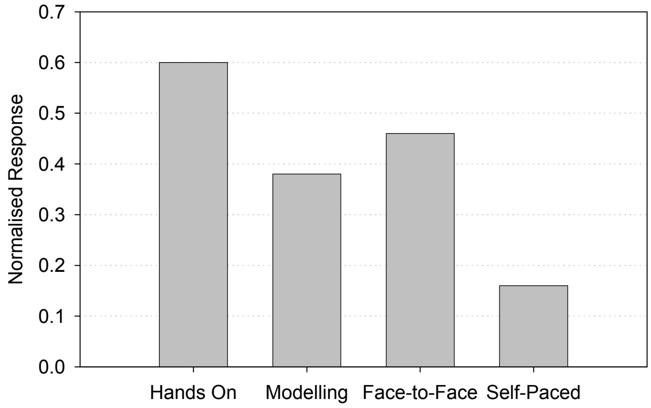

Figure 6: Preferred methods of learning

Conclusions

From the results of the survey conducted, the program structure in place at RMIT has the ability to address the deficiencies of student knowledge and skills. At the same time building on student strengths and through continual program development, new skills and concepts of MEMS technology can be learnt to develop the necessary skills needed for the Australian Microtechnology industry.

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Prototype Educational Tools for Systems and Software (PETS) Engineering

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Abstract: *This paper briefly discusses the problem of poor requirements and how, while solutions are known, they are not being transferred from academia to industry. The paper then discusses a project to implement an approach for transferring the solution from academia to industry by using the Blackboard principles of Artificial Intelligence and software Agents to provide a suite of evolving educational tools based on an object-oriented information systems paradigm. The paper then gives an overview of the functionality provided by the tools, some early results and a list of the expected benefits of the project.*

Keywords: *Requirements engineering, postgraduate education, tools*

Introduction

The systems and software development industry is characterized by a paradigm of project failure (Standish 1995). The situation has been described by Cobb's Paradox (Voyages 1996), which stated "*We know why projects fail, we know how to prevent their failure --so why do they still fail?"* While the problem of poor requirements engineering and management has been repeatedly and widely discussed and documented for at least 10 years as a contributing cause of project failures (Hooks 1993; Kasser and Schermerhorn 1994; Jacobs 1999; Carson 2001; etc.), the continual documentation and discussion of the problem of poor requirements engineering and management has not resulted in a practical solution to the problem.

The PETS project

This paper discusses a project for the development and use of a suite of prototype educational tools for systems and software (PETS) engineering that:

- Have the potential to transfer the solution to the problem of poor requirements management from academia to industry and consequently reduce cost and schedule overruns.
- Are as simple to use as a slide rule.

- Can be used in the classroom and in the workplace.

The development of these tools and accompanying classroom materials is known as the PETS project.

Background

Research into the cause and effect of the problem of poor requirements management has shown that the current focus of systems and software engineering on improving the written text of the requirement is an important but incomplete solution to the problem. Moreover, there has been recent recognition that a requirement is more than just the imperative statement. For example both Alexander and Stevens (2002) and Hull et al. (2002) discuss additional attributes of a requirement in conjunction with improving the writing of requirements. However, in practice, there is difficulty in adding these additional attributes to the traditional requirement document or database. This is because the current systems and software development paradigm generally divides the work in a project into three independent streams – Management, Development, and Test (Quality) (Kasser 1995). Thus requirements engineering tools contain information related to the Development and Test streams (the requirements) while the additional attributes tend to be separated in several different tools, e.g. (Requirements Management, Project Management, Work Breakdown Structures, Configuration Control, and Cost Estimation, etc.).

Expanding the scope of the requirement

After research into reasons for project failures (Kasser and Williams 1998), and the management of change over the System Life Cycle (SLC), Kasser (2000) used an object-oriented approach within an information system paradigm to derive the additional attributes of a requirement needed to alleviate the expensive cost and schedule impacts and proposed the following set of Quality System Elements (QSE) as being necessary for effective system and software development:

- Unique identification number - the key to tracking.
- **Requirement -** the imperative construct statement in the text mode, or other form of representation.
- **Traceability to source(s) -** the previous level in the production sequence.
- **Traceability to implementation -** the next level in the production sequence. Thus requirements are linked to design elements, which are linked to code elements.
- **Priority -** knowing the priority allows the high priority items to be assigned to early Builds, and simplifies the analysis of the effect of budget cuts.
- **Estimated cost and schedule -** these feed into the management plan and are refined as the project passes through the SLC.
- **The level of confidence in the cost and schedule estimates** - these should improve as the project passes through the SLC.
- **Rationale for requirement -** the extrinsic information and other reasons for the requirement.
- **Planned verification methodology(s) -** developing this at the same time as the requirement avoids accepting requirements that are either impossible to verify or too expensive to verify.
- **Risk -** any risk factors associated with the requirement.
- **Keywords -** allow for searches through the database when assessing the impact

of changes.
- **Production parameters -** the Work Breakdown Structure (WBS) elements in the Builds in which the requirements are scheduled to be implemented.
- **Testing parameters -** the Test Plans and Procedures in which the requirements are scheduled to be verified.
- **Traceability sideways to document duplicate links -** required when applying the QSE to an existing paper based project.

The information in the QSE is related to all three streams of work in a project because the underlying concept for the QSE is that the three streams of work are interdependent not independent. It is a different paradigm to the one that has produced the current generation of Requirements Engineering and Project Management tools. Thus importance and value of the additional attributes of a requirement are discussed in textbooks and the set of attributes defined as the QSE are taught in the postgraduate classroom in UniSA. However, while practitioners publish, and academia teaches, what the students "should" do, the current generation of requirements engineering tools do not allow the students to use that knowledge, and hence there is no (easy) way for the students to see how the QSE improve the current paradigm, and consequently the new knowledge is not used outside the classroom which means that the problem of poor requirements management remains.

Baseline for the PETS project

The baseline for the PETS project is the need to improve the effectiveness of postgraduate education in the information technology (IT) industry and the sum of previous products and experience as described below.

The need to improve the effectiveness of postgraduate education in the corporate environment
The knowledge explosion of the early 21st century has given rise to the situation in the IT industry in which the half-life of the knowledge needed to do a particular job can be as short as two years. This has resulted in the need for continual education and life long learning. Corporate employees are thus faced with the problem of acquiring new knowledge while at the same time performing on their job, and meeting their family and other non-corporate lifestyle duties. A goal of the project is to improve the effectiveness of postgraduate education for students in the corporate environment in the IT industry. The PETS should assist in the resolution of Cobb's paradox by increasing the effectiveness of requirements engineering and management, while minimising classroom learning time.

The Requirements Workshop at University of Maryland University College
The requirements workshop was held as part of postgraduate courses in Software Engineering at University of Maryland University College (UMUC). The workshop
- Discussed the problems resulting from poor requirements.
- Provided examples of poorly written requirements.
- Provided a set of requirements for writing requirements (Kasser 1995).
- Asked the students to read and evaluate an instructor-supplied requirements document to determine the number of good and bad requirements in the document.

The Student Enrollment and Course Tracking System (SECTS)
The SECTS provided students in the requirements, design and development, independent validation and verification (IV&V), and software maintenance postgraduate courses in

Software Engineering and Computer Systems Management at UMUC with different perspectives of the same system (Kasser and Williams 1999). The approach used was to create paper documents for various aspects of the same system. Thus the requirements class created a requirements document, the design classes created design documents, the IV&V class created test documents, and the software maintenance class created a software maintenance plan. The PETs will be used to create similar documents in classes at UniSA, but will emphasize the underlying QSE by treating the documents as views or printouts of the information in the database rather than stand-alone paper-based products.

The Suite of Agents concept

The Agent based approach of using a suite of software products for rapid software evolution based on a domain model was presented as a way to develop software that is quicker and less expensive to maintain (Glover and Bennett 1996). Kasser (2000) also described the concept of a suite of tools for accessing the information in the QSE. Kasser and Cook (2003) discussed the projected implementation of the suite using a rapid incremental solution construction approach, which maps into both the Blackboard and Agent based approaches.

The First Requirements Elucidator Demonstrator (FRED)

An early prototype of FRED was presented by Kasser (2002) as a tool that ingested requirements from documents and identified potential defects in requirements by parsing the text for the presence of a set of "poor words". FRED was based on automating and improving the manual process performed during the Requirements Workshop at UMUC. FRED produced a Figure of Merit (FOM) for the document. The FOM is a simple one-dimensional measurement for the quality of a document based on the presence or absence of "poor words". The FOM allows comparisons to be made of the quality of documents of different sizes. The FOM was calculated using the formula

$$FOM = 100 * (1 - \text{number of defects} / \text{number of requirements}).$$

The prototype educational tools for systems and software (PETS) engineering

The plan is to develop and use an initial simple suite of tools with a similar user interface. The tools would then continue to evolve into intelligent agents using the Blackboard approach as more is learnt about their use. After some analysis of how, and when, the

Tool	Functionality	Course			Release
ACE	Acceptance Criteria Elucidator		T		0.8
ANT	AssistaNt for Test plan generation		T	P	0.3
BULL	BUild pLanning tooL			P	-
COCK	COnfiguration Control Keeper		T	P	-
COW	COst profiling Wizard			P	0.2
CRIP Charter	CRIP Chart generator			P	-
ET	requirement Enhancing documentation Tool	R			0.2
Max	Requirements completeness MAXimiser	R			0.1
RAT	Risk documentation And profiling Tool	R		P	0.1
RP	Requirement Priority documentation tool	R		P	0.2
SRR	System Requirements Review report generator			P	-
TIGER	Tool to InGest and Elucidate Requirements	R	T		1.15
TPA	Task Planning Assistant			P	-
WORM	Wizzard for pOor Requirement reforMatting	R	T		-

Table 1: The initial set of PETS

management and technical information in the QSE is used in the SLC, the access to information was partitioned and Table 1 shows the tools that were identified as candidates for the initial suite.

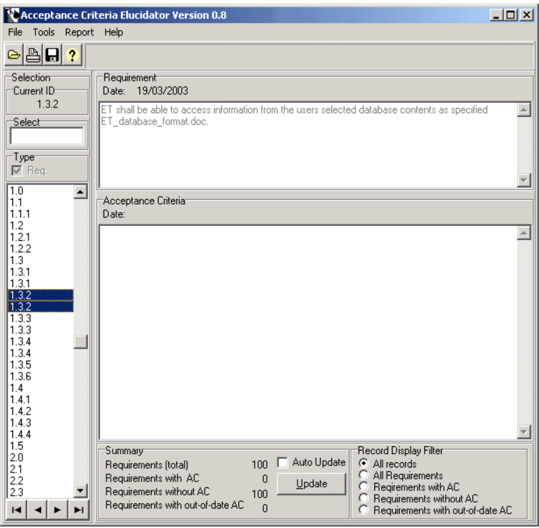
Each tool is currently targeted for use in one or more of the following postgraduate courses

- **The Requirements (R) course** covers the ingestion, writing, elucidation, and the allocation of key words to requirements for ease of database searches.
- **The Test and Evaluation (T) course** covers the addition of acceptance criteria and plans for testing the requirements.
- **The Software Engineering Project Management (P) course** covers risk, priority, cost, allocation of requirements to builds, and configuration control.

Each tool accesses the same QSE database (and, in some cases, its own database) providing generic selection, reporting, and sorting functionality. The specific functionality provided by the initial version of each of the tools is outlined below in alphabetical order. In addition, each tool provides the appropriate printed reports.

Acceptance Criteria Elucidator (ACE)

ACE allows the user to create, view, add, and modify acceptance criteria for requirements in the QSE database. ACE also provides a printout of each requirement in the database together with its acceptance criteria. The main user interface screen for the tool is shown in Figure 1.



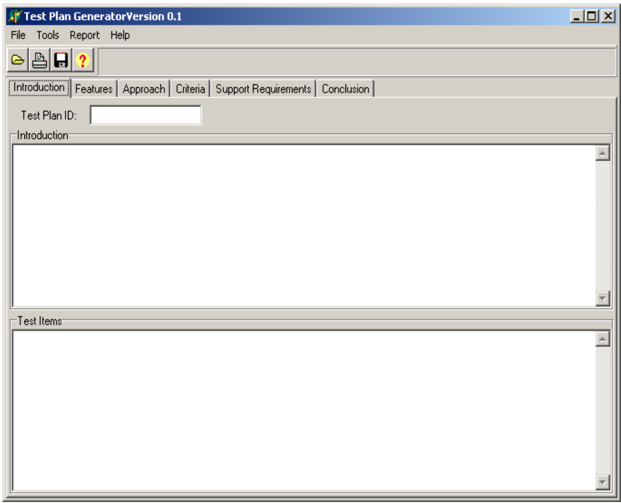


Figure 1: ACE

Figure 2: ANT

AssistaNt for Test plan generation (ANT)

This tool

- Creates sections of a test plan in accordance with IEEE Standard 829-1998.
- Facilitates grouping of tests.
- Links acceptance criteria to tests.
- Documents the estimated cost to perform the test.
- Documents traceability of the test to specific requirements.
- Documents the test equipment needed.
- Documents the schedule for the tests.
- The main user interface screen for the tool is shown in Figure 2.

BUiLd pLanning tool

This tool allows the user to create, view, document and modify

- The Builds to which requirements are assigned.
- The estimated cost of the Build.
- The priority of the requirements assigned to the Build.

COnfiguration Control Keeper (COCK)

This tool allows the user to view, modify and create, the following information

- Change request unique identification number.
- Criteria to show that change has been implemented.
- Product/Build Identification.
- Change request text.
- Change request Disposition.
- Change request Priority.
- Impacted requirements.
- Product/Build Number in which change will be implemented.
- Request allocated to CCB meeting date.
- Actual date of CCB Meeting.
- Reason for acceptance or rejection.
- Key words.
- Impact assessment identifier.
- Reporting functions for configuration control information.

COst profiling Wizard (COW)

This tool, shown in Figure 3, allows the user to create, view, document and modify

- An assigned cost to each requirement.
- The rationale for the cost.
- The accuracy of the cost.
- The total cost (high, mean, and low) of the set of requirements.

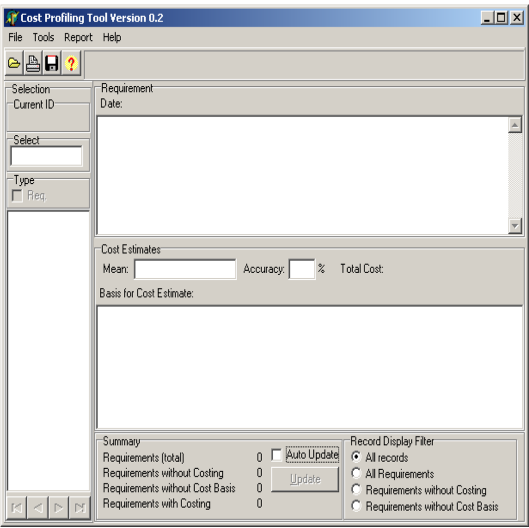


Figure 3: COW

CRIP Chart generator

This tool allows the user to view, modify and create Categorized Requirements in Process (CRIP) charts for measuring project progress (Kasser 1997). The CRIP approach is to:

- Identify a number of categories (e.g. complexity, risk, estimated cost, priority, etc.).
- Quantify each category into ranges (e.g. 1-10, A-J, etc.).
- Assign each of the requirements into one or more categories.
- Place each requirement into the assigned range in its category (e.g. complexity range 3, cost range 4, priority range 5).
- Monitor the changes in the state of the production work attributed to each of the requirements between the SLC reporting milestones and look for specific items discussed in Kasser (1997) to answer the question "how much of my project has been completed?"

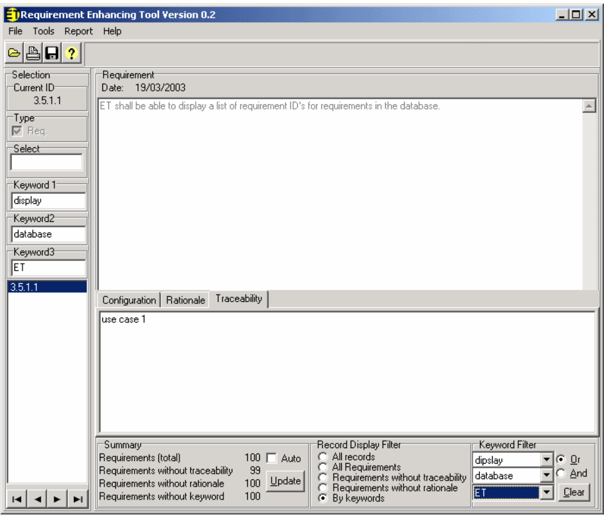


Figure 4: ET

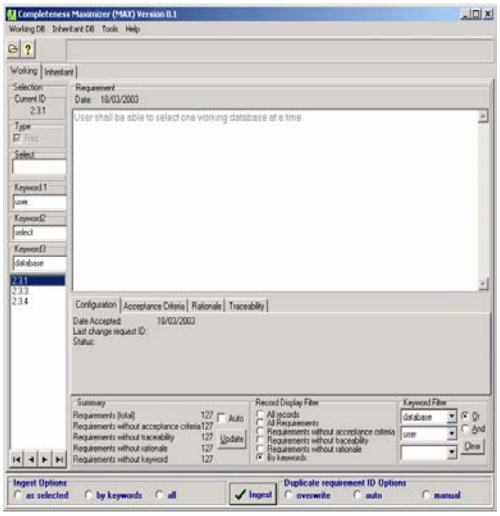


Figure 5: MAX

requirement Enhancing documentation Tool (ET)

ET shown in Figure 4, provides for the viewing, addition, modifying, and reporting, of the following QSE

- Keywords
- Rationale for the requirement
- Traceablity to source(s) and sideways

Requirements completeness MAXimiser (MAX)

The main user interface screen for the tool is shown in Figure 5. Max allows the user to add, view, and modify requirements, and to inherit requirements from a second QSE or requirements database. Max can be used to inherit requirements from a similar system. For example:

- Some of the requirements for one PET can be inherited from a previous tool database (e.g. user interface requirements).
- When developing requirements for a specific type of system (e.g. communications satellite), non-functional requirements for the object class of communications satellites can be inherited (thermal vacuum, humidity, and vibration) hence maximizing the completeness of the requirements for the specific instance being constructed.

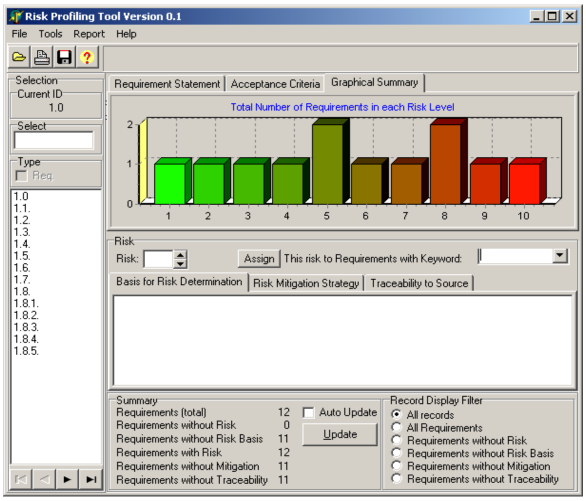
Risk documentation And profiling Tool (RAT)

This tool allows the user to view, document and modify

- An assigned risk (1-10) to each requirement.
- The rationale for the risk.

- The risk mitigation strategy.

The tool also displays the total risk as a Pareto chart to provide a visible risk profile as shown in Figure 6.



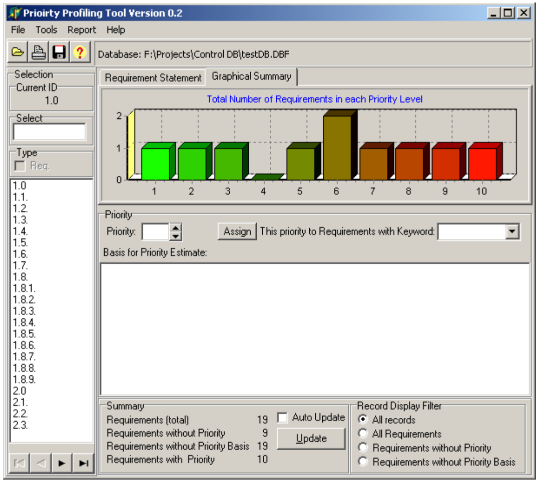


Figure 6: RAT

Figure 7: Requirement prioritising tool

Requirement priority documentation tool (RP)

This tool allows the user to view, document, and modify, an assigned priority (1-10) to each requirement. The tool also shows the total priority profile as a Pareto chart identifying the number of requirements in each range of priority. The main user interface screen for the tool is shown in Figure 7.

System Requirement Review (SRR) report generator

The SRR report generator provides reports on QSE information provided by other tools in the suite. These are

- Requirements and acceptance test criteria from ACE.
- TIGER Figure of Merit.
- System Risk Profile.
- Task plans.
- Test plans.
- Cost estimates.
- Build plans.
- CRIP charts.

Tool to InGest and Elucidate Requirements (TIGER)

TIGER performs the following functions

- Ingesting of requirements from text documents and the keyboard.
- Modification of existing requirements.
- Elucidating requirements based on a set of “poor words” and points out up to six types of (potential) defects in each of the requirements (multiple requirement in a paragraph, possible multiple requirement, unverifiable requirement, use of “will” or “must” instead of “shall”, and the existence of a user defined “poor word”).
- Allowing for additional “poor words” to be added as they are identified.
- Allowing for “poor words” to be used in a requirement when their use is appropriate. For example, the requirement that “the system shall display the

combined total of A <u>and</u> B" is a good requirement.

- Providing a built-in agent using deterministic grammar for the engineering of requirements (BADGER) that facilitates the correct format for writing requirements by, prohibiting many "poor words", and minimizing the need for retyping by the use of drop down lists (Scott 2003).
- Producing a report documenting each occurrence of a "poor word" in the requirements.
- Producing the FRED FOM.

The main user interface screen for the tool is shown in Figure 8.

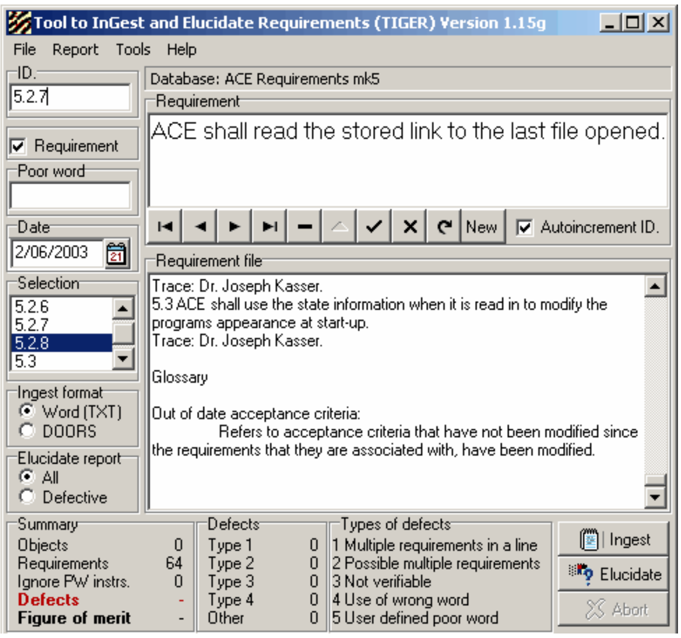


Figure 8: TIGER

Task planning assistant (TPA)

For each task in the project, this tool allows the user to create, add, view, and modify the

- Name of the task;
- WBS number;
- Requirements (identifications), upon which the completion of the task is derived;Priority of the task, based on the priority of the requirement;Name of person responsible for performing the task;WBS subtask elements within the task;
- Name of person generating the task;
- Reasons why the task is being performed;Key milestones;
- Previous (prerequisite) tasks;
- Subsequent (dependent) tasks;
- Decision points (what decisions need to be made and why);
- Risks;
- A written narrative description of what the task will accomplish and an outline of how the task will be performed;
- An estimated time frame (schedule) to perform the task (start and completion dates, minimum, most probable, and worst case times);
- A list of pre-requisites governing the start of the task (products);

- A list of personnel resources needed for the task (skills and skill-levels);
- Extent and level of effort by each personnel resource (team member);
- Cost estimates to perform the task (minimum, most probable, and worst case);
- A list of equipment resources needed to perform the task;
- A list of anything else needed to perform the task;
- A list of the products produced by the task;
- A suggested list of evaluation criteria for measuring the effectiveness of the task.

Wizard for poor Requirement formatting (WORM)

This tool assists test planning and facilitates ensuring the completeness of testing by converting written requirement paragraphs containing multiple requirements into separate requirements. As an example of the work that this tool can expedite, consider the following requirement (ST-DADS 1992):

204.1 `DADS shall automatically maintain statistics concerning the number of times and the most recent time that each data set has been accessed. These same statistics shall be maintained for each piece of media in the DADS archive.`

The tool splits this requirement into the following four requirements to simplify tracking the completeness of the test plans:

204.1a DADS shall automatically maintain statistics concerning the number of times ~~and the most recent time~~ that each data set has been accessed. ~~These same statistics shall be maintained for each piece of media in the DADS archive~~.

204.1b DADS shall automatically maintain statistics concerning ~~the number of times and~~ the most recent time that each data set has been accessed. ~~These same statistics shall be maintained for each piece of media in the DADS archive.~~

204.1c DADS shall automatically maintain statistics concerning the number of times ~~and the most recent time~~ that ~~each data set has been accessed. These same statistics shall be maintained for~~ each piece of media in the DADS archive [has been accessed].

204.1d DADS shall automatically maintain statistics concerning ~~the number of times and~~ the most recent time that ~~each data set has been accessed. These same statistics shall be maintained for~~ each piece of media in the DADS archive [has been accessed].

Leaving the sections of the requirement that were not being tested in place but stricken through clearly identifies which section of the requirement is being tested. An unfortunate side effect is that it also clearly shows the defects in the requirement. Note that the phrase '`has been accessed`' has been moved in the last two sub-requirements to clarify the sub-requirement.

Educational materials

The purpose for the tools is that they are to be introduced in the educational environment. Hence the following additional documentation is being generated for each tool.

- Help files in Windows 'hlp' format
- Installation software
- Sample databases and documents
- PowerPoint presentation and lecture notes for use of tools in class.

The Benefits of the PETS project

The benefits of the PETS project are, it should:

- Reinforce the concept and usefulness of the QSE by providing a way to use them.
- Provide tools for the students to use in class and in the workplace.
- Provide new views of integrated management and technical information, e.g., cost and priority.
- Allow (new) questions to be raised before major project funds are committed, e.g.:
- What is a good risk profile for a project?
- Does customer really want a low priority high cost requirement?
- Provide a baseline for a platform of opportunities for further research in areas such as complex systems, artificial intelligence, expert systems, project management and education. Follow-up on the use of the tools in the workplace by the students will be required to determine if the suite of tools makes a difference.

Early results

The tools are still under development. TIGER was the first tool to be used in a class lecture on requirements engineering in three postgraduate courses. Before TIGER, the discussions in the tutorials focussed on the structure and format of requirements. After TIGER was introduced and used to elucidate sample requirements, the focus of the in-class discussions changed to cover the difficulties of writing good requirements. Further research is in progress.

Summary

This paper briefly discussed the problem of poor requirements and how, while solutions are known, they are not being implemented in industry. The paper then discussed an approach for transferring the solution from academia to industry by using the Blackboard principle of Artificial Intelligence to provide a suite of evolving educational tools based on an object-oriented approach to requirements engineering and management within an information systems paradigm. The paper then gave an overview of the functionality provided by the tools and concluded with a list of the potential benefits of the project and some early results of the use of the TIGER tool.

Availability of the PETS

The PETS that have been tested in the educational environment, and released, can be obtained by accessing the Systems Engineering and Evaluation Centre website (http://www.seec.unisa.edu.au) and following the link to Software Tools. The PETS are provided free for educational purposes.

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Acknowledgements

The authors acknowledge Professor Stephen Cook's suggestions for a number of the acronyms for the PETS, and William Scott's sharing of concepts from his PhD research.

Flowchart Software for a Modular Robot

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Abstract: *Flowcharting is a common method of setting out the requirements for a piece of code. It is simple with few rules to follow. Rarely however, is it used as the code itself. This paper describes the outline of a software package that uses the flowchart as the code for a small, autonomous, modular robot, designed for use in High Schools and Universities at an introductory level.*
By using flowcharting the student is introduced to the concept of structured programming. A flowchart is often the first step in programming. Here it is the only step, easing the student into the art of coding, and simplifying the teachers job.

Keywords: *Robotics, Educational software, Flowchart*

Introduction

During a project the author had at a high school that involved enabling a small group of students to build a robot that could move over a piece of paper, drawing as it went, a discussion developed between the author and the teachers. The point of the discussion was that the teachers were looking for a robot system that could take the students beyond the Lego "Mindstorms" robot. The "Mindstorms" robot was too limiting with only 3 inputs and 3 outputs. The teachers found that some of the students mastered this robot to easily are required a more flexible robot to continue their learning progression. The result was a small, autonomous, modular robot that the students could plug together in any configuration.
One hurdle in this robot system was the programming of the robot. The teachers did not want a programming language that would take too long for the teachers to learn and so it was decided to use flowcharting, which the teachers had experience with, as the language.

This software package was written to allow high school students to program a small modular robot with little or no previous experience. The robot itself was designed to be studied after the students had had some experience with the Lego "Mindstorms" robot system.

This meant that the students should have had some ability with programming with icon-based, flowchart-like systems. This also had a bearing on the decision to use flowcharting as the method of programming.

Other Flowcharting software

As the Flowcharts were to be a stage that followed the Lego Mindstorms icon based system, the author looked in this area and found the "Chart Programming Language".(Gilder 2001) This is a flowchart based system. Unfortunately on a more detailed examination it was found that the system allowed the student to write a flowchart then to write the code from the flowchart. As one requirement was too just use the flowchart itself as the code, this option was discarded.

Dr. Tia Watts from the Sonoma State University is working on a flowchart editor.(Watts 2002) This is just a GUI flowchart editor, but could be turned into a compiler with a little more work. It is very comprehensive but was a little to detailed for the job at hand.
Matrix Multimedia has a very promising package called “Flowcode”.(Matrix Multimedia Limited 2002) This package allows students to design complex electronic systems straight from the Flowchart. Its output is used to program a PIC microprocessor. It is however, very detailed, found to take a while to learn and a different processor had already been chosen for the modular robot.

Inhouse Software

In the end, it was decided that the author would write this software. This gave the author full control over the code and no licensing issues. As the author also had to write the code that resided in the robot, it was easy to ensure compatibility and to make the job easier.

The Robot

To write the software, a little needs to be known about the robot it is interfacing to. The Robot has 16 addressable 1 byte inputs and 16 addressable 1 byte outputs. Inputs and Outputs, known as Ports, are for the sensors that the students attach to the robot. The robot also has 4 motors and a timer system.

Figure 1: The modular robot

The Robot’s code

To simplify the programming job for the students, it was decided to let the robot’s code do as much as possible. The robot used the 68HC08 microprocessor with 1K of RAM, 512 Bytes of EEPROM and 32K of Flash memory. The download and Flash programming code resides in the EEPROM as no code is allowed to run in Flash while it is being programmed. The download code accepts S19 files for programming.
The beginning of the Flash was reserved for the student program whilst the remaining code sat in the last bit of Flash. This code had a standard loop that would continuously run the students code. The main part of the code is in an interrupt routine that occurs every 20ms. The routine updates the Pulse Width Modulation signal for each of the motors from the data

in a series of memory locations. It updates the 16 output ports from more data in memory and reads the 16 inputs ports and save the data in memory. It also increments the timer system.

The Software

With the robot's code handling all of the robot's system from data in memory, all that the student's code needed to do was access and manipulate the memory. The various memory registers can be seen in the following dialog box.

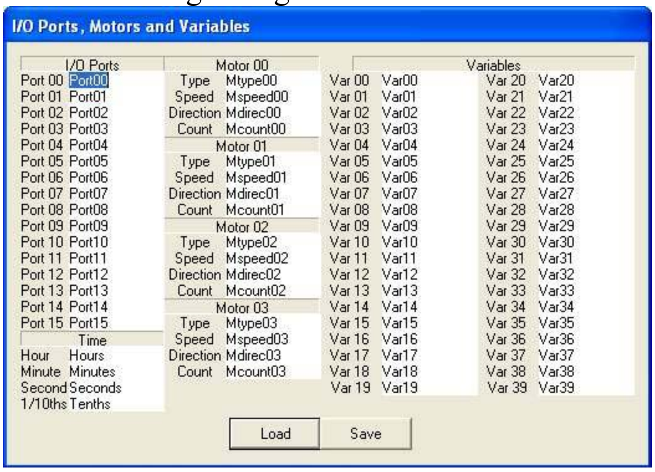

Figure 2: The available memory locations

There are the 16 input/output ports, the time registers, the 4 motor registers and 40 variable registers. In this dialog box we see that each address is given a default name that can be changed by the student to make more sense. For instance, If port00 is a Light Dependant Resistor (LDR) on the left side of the robot, its name could be changed to LDR_Left.
This greatly simplified the job of the complier in the software and it simplified the Flowchart required. The Flow chart has two basic blocks, a process block and a decision block.

The Process Block

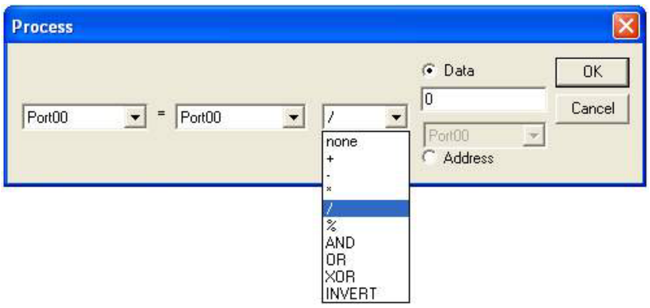

Figure 3: Process dialog box

The above dialog box shows the basis of the process block. It allows the student to set any of the memory locations to any arithmetic or logical combinations of other memory locations or data.

The Decision Block

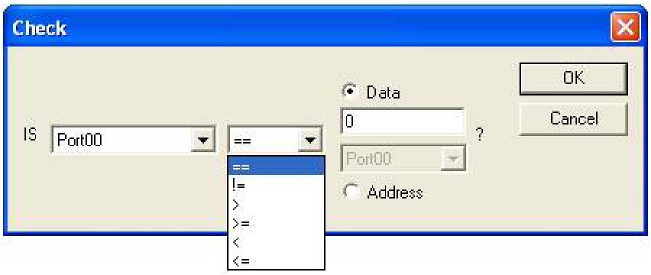

Figure 4: Decision dialog block

As can be seen here, any memory location can be compared to any other location or data and a decision can be made on the outcome.

A typical Flowchart would look like this:

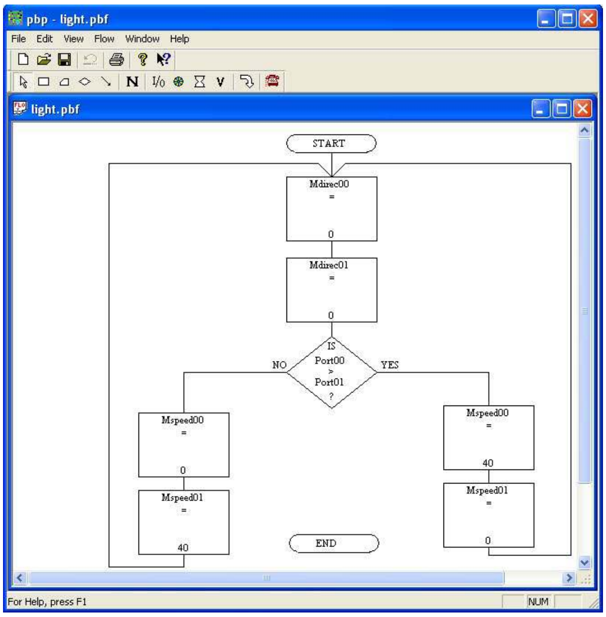

Figure 5: The software with a flowchart example

This Flowchart sets the direction of the motors and then compares input ports 0 and 1, turning the robot one way or the other by setting the motor speeds. If ports 0 and 1 were LDR sensors, then the robot would seek light. Note that the End block is not reached. Each flowchart requires a Start and End block. This flowchart never ends.

The Run Block

Figure 6: Run dialog box

While this Flowchart is fairly simple, more complex Flowcharts are possible. To this end, a Run Block was added. The run block simply calls a flowchart that has been saved as seen in the following example.

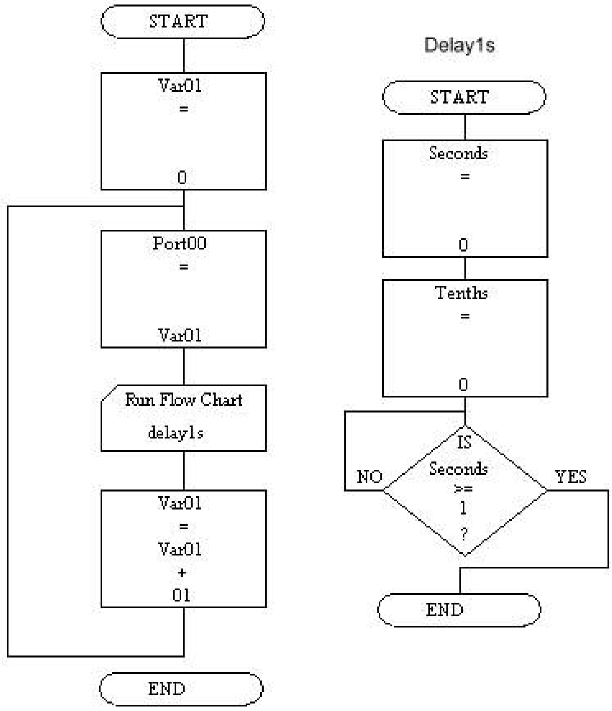

Figure 7: Example of flowchart calling another flowchart

The flowchart on the left increments a variable in a continuous loop. In that loop a Run Block calls the Flowchart on the right, which creates a one second delay. Thus the variable is incremented once per second.

Compiling and Downloading code

Once the Flowchart is drawn the student selects download. As it was decided that the flowchart was to be the program as far as the student was concerned, all processing from this point is hidden from the student. First the software compiles the flowchart in a two pass process. Because of the limited number and variation of blocks, each possibility is precompiled. Thus the compiler just selects the required code, inserts the memory location or data and ends the block with a jump to the next block or blocks. The second pass inserts the jump addresses.

This done, the software creates the S19 record and then uses the MSComm routines to download the code, via a serial port, to the robot.

The serial port was chosen over USB as all high schools will have serial port on their PC's while only the most up to date schools will have PCs with USB. In the worst case, a school with only USB can get USB to serial converters very cost effectively.

While serial communications is more complex under Windows 95 and later, it also has a greater capability.(Mirho 1996) Or does it?

Communications

The biggest problem the author had in writing this software was with the Serial port communications. The software was written using Microsoft's Visual C++ as the author was most familiar with this language. The creators of the MSComm routines wrote these routines for Visual Basic and Microsoft converted them for Visual C++. This means that there is very little support and documentation for them and the author found that a lot of trial and error was required to get these routines to work correctly. For example, the comm. Port likes to shut itself down and so the software must regularly check if the port is closed and reopen it.

The Student

The challenge for the student is two fold. As the robot is modular, the student must be able to assemble the robot in the correct configuration for the chosen task. (This aspect is not covered in the paper.) That done, the student must use the limited flowchart blocks available to create the correct flowchart to enable the robot to complete the task. As each input and output module has an address which the student chooses, the student must learn about address busses. This in turn can be used to teach data and control busses.

Once the student knows how to address the input and output modules, the student is able to begin flowcharting. As the flowchart block deal only with simple arithmetic and logic functions, the student must learn to use these fundamental operations to design functional flowcharts that can perform a specific task, such as controlling a motor and creating a time delay. This is similar to how a student learning to program in assembly language must learn, thus the student is being prepared for further programming studies at a later date.

The functional flowcharts can now be pieced together to create an operational flowchart.

For advanced students, including secondary and tertiary students, the flowchart language can be bypass and any language, such as assembly or C, can be used as the robot itself does not accept the flowchart but S19 files which are an industry standard for the programming of microprocessors. Thus any complier that can create S19 files for the robots Microcontroller, the M68HC05, can be used.

Current Field Trails

There are currently six prototype robots at Brauer College in Warrnambool. The students there have taken to the robots very readily. Preliminary verbal feedback is that the students have accepted the robots and enjoy working with them. They prefer them to the "Mindstorms" robots because they are able to do more with them.

Although the science teachers use the robots in the robotics subject, the computer teachers now want their students to use the robots as they find the robot flowcharting system as a good way to introduce their students to structured programming and because the robots also provide an introduction to computer architecture.

Conclusion

The author found this project to be a challenging but thoroughly enjoyable exercise. It pointed out to him, again, that writing code that talks to external devices, especially one off devices such as this projects robot, is one of the harder types of code to work on.

The robot designed gives the teacher a structured environment in which to teacher the fundamentals of programming in a manner that can capture the students attention and thus allows both the teacher and students to obtain more out of the learning process.

The robot affords an introduction to robotic principles, structured programming, and computer architecture in a fun and an easily approachable way. The robot can also be used as a robotic base for secondary and tertiary students. Its modular approach and industry standard programming system, allow it to be used as both an introductory robot and a robot for advanced learning.

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Teaching Digital Signal Processing Using MATLAB

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Abstract: *This article presents an overview of a Digital Signal Processing (DSP) course, based on usage of MATLAB software to support teaching. DSP can be taught at different levels and students need sound mathematical skills. MATLAB is used as a suitable, interactive, programming language and development environment. It is utilised as a tool to support teaching mathematical theory, physical principles and also to develop real life applications. Principles of safety, sound relationships, sequence and reinforcement, praxis, respect for learners, ideas, feelings, actions, immediacy, clear roles, teamwork, engagement and accountability, important for adult teaching, have been used in the course design. By doing projects, students learn how to perform MATLAB programming, learn something about hearing and produce a product that can be used by non-professionals. This paper also presents and discusses the finding of the course evaluation. Student feedback results are presented graphically.*

Keywords: *DSP, Screening Test, Hearing Aid*

Introduction

There are many books about Digital Signal Processing, available to be used as textbooks, or reference books: such as one from Richard (1990), together with a very useful, Analogue Devices application book (1990). There are also relatively new ones, like ‘Solving engineering problems with MATLAB’, Dolores (1997), or one from James, Ronald and Mark (1999), with a multimedia approach. Thomas (2000), covers theory in great details, while Childers (2000), treats a specific area of speech processing. There are also many online DSP courses available on the Internet, as well. To do the actual DSP chip programming one has to use an assembler, C, MATLAB, or some other language.

DSP is a complex subject as this variety of resource material shows. A decision was made in this course, to support theory using a new, modern, interactive and powerful tool called MATLAB, as much as possible. In addition to doing revisions on complex numbers, trigonometry, Euler’s formulas, powers and roots, students are encouraged to use MATLAB as a scientific calculator, interactively.

- By following a schedule, and a sequential approach, described in this paper, the educational principle of Sequence and Reinforcement is applied.
- By asking students to start designing useful applications from the very beginning, the principle of praxis is applied.

- By interaction during the course, and asking students for their evaluation of the course, respect for learners, as subjects of their own learning, is shown.

Most of the projects are designed and given to students as team exercises. Andragogy suggests that the teaching role should be more responsive and less directive, Knowles, Burns (1995). According to that, students have their say about methodology, assessment techniques, content, as well as program design.

MATLAB as a DSP tool

MATLAB (matrix laboratory*)* is a language for technical computing, that integrates computation, visualisation, and programming. Problems and solutions are expressed in mathematical notation. MATLAB is typically used for math and computation, algorithm development, modelling, simulation and prototyping, data analysis, exploration, scientific and engineering graphics and application development including "Graphical User Interface" building.

MATLAB is an interactive system whose basic data element is an array. This allows us to solve many technical computing problems, especially those with matrix and vector formulations. It is easier than using languages like Fortran, or C. MATLAB is a comprehensive, programming, interactive environment. Using an API (Application Programming Interface), it is possible to write C and Fortran programs that interact with MATLAB, which means that we can use our own programs, written before, for existing applications. MATLAB also features a family of application-specific solutions called *toolboxes*. Toolboxes are collections of MATLAB functions, or M-files, that extend the MATLAB environment to solve particular classes of problems, like: signal processing, control systems, neural networks, fuzzy logic, simulation and others.

An additional component to MATLAB is *Simulink* that can be used to simulate non-linear dynamic systems. It is a graphical, mouse-driven application that allows us to model a system by drawing block diagrams on the screen, and manipulate them dynamically. It can work with linear, non-linear, continuous-time, discrete-time, multivariable, and multirate systems. *Blocksets* are add-ons to Simulink that provide additional libraries of blocks for specialised applications. *Real-time Workshop* is an application that allows us to generate C code from block diagrams and run it on a variety of real-time systems.

In university environments, MATLAB is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science.

Sequence and Reinforcement - from Analogue to Digital World

The principle of Sequence and Reinforcement is used to educate students how transition from analogue to digital signals takes place. Once the signals are in digital form, Digital Signal Processing Techniques can be applied.

Harmonic signals revision Students in the class express their needs by requesting an appropriate level of revision to be done, to support each learning unit.

The next step, following basic math, is to study signals, and to explain to students, transition from analogue to discrete domain using the principle of Sequence and Reinforcement.

Let us consider the following signal:

$$x(t) = A\cos(w_0 t + \Phi) \qquad (1)$$

The basic equation (1), where

A represents a amplitude, in [unit] according to the physical quantity,
w_0 is radian frequency, in [rad/sec]
t is the time, in [sec] and
Φ is phase shift, in [rad],

could be rewritten as following:

$$x(t) = A\cos(2\pi f_0 t + \Phi) \qquad (2)$$

where f_0 is cyclic frequency, in [Hz = 1/sec] and as known

$$w_0 = 2\pi f_0 \qquad (3)$$

The next step would be to introduce sampling period T_s, and index n, as

$$x(t) = A\cos(2\pi f_0 n T_s + \Phi) \qquad (4)$$

where T_s can also be represented as $1/f_s$, which finally gives

$$x(t) = A\cos((2\pi f_0/f_s)n + \Phi) \qquad (5)$$

Students put this all into MATLAB programs that they design so that they can apply what they are learning to a real situation.

In their programs, apart from implementing basic expression (5), students are encouraged to try different sampling rates, frequencies, durations, amplitudes and listen to the sound, as well as, look at generated plots. By doing so, they can research what happens with signals when over-sampling or under-sampling is implemented. They are also encouraged to generate the sum, or product of signals and analyse outcomes.

Expanding what Vella (1994) has stated regarding praxis as a process of doing – reflecting – deciding – changing – new doing, students are asked

1) What do you see and hear happening, and how does that relate to your practical skills and knowledge?
2) Why do you think it is happening, what do you think will happen, before you do some changes, and do the changes as much as possible. Analyse and do something else, many times.
3) When it happens, in our case under-sampling, for example, what problems does it cause (folding, harmonics…)?
4) What can we do about it to prevent, or to implement it?

Students produce different programs and use them as tools to analyse the physics behind events. They have full freedom in their design, while following only syntax rules for MATLAB. At the same time they are encouraged to improve design by enforcing known good practices.

An example of the program is shown in Figure 1.

```
%   Sampling rate study, spectrum study
Fs=8000;        %   Sampling Rate
T=2;            %   The length of the signal in seconds
F0=800;         %   Frequency of the signal in Hertz
Ph=-pi/2;       %   Phase of the signal in radians
A=0.1;          % Amplitude of the signal
n=0:(T*Fs)-1;   %   Index vector, dimensionless
Y1=A*cos(2*pi*F0/Fs*n+Ph);          %   Generating a signal
Y2=A/2*cos(2*pi*2*F0/Fs*n+Ph);      %   Generating another signal
Y=Y1+Y2;
%
sound(Y,Fs)                         %   Playing the sound
figure(1)                           %   Preparing to plot signals
subplot(3,1,1)
plot(Y1(1:100))
title('Signal Y1, signal Y2 and signal Y=Y1+Y2')
subplot(3,1,2)
plot(Y2(1:100))
subplot(3,1,3)
plot(Y(1:100))
%
Yf=fft(Y);                          %   FFT of the signal
f=linspace(0,Fs*(1-1/(Fs*T)),length(n));  % Frequency axis values
figure(2)                           %   Preparing to plot spectrum
plot(f,abs(Yf)/length(n)*2)         % Plots the magnitude
title('Spectrum content of the signal')
xlabel('Frequency')
ylabel('Amplitude')
axis([0 Fs/2 0 2*A])
```

Figure 1: Example program that can be used to analyse sampling and signal spectrum

In this simple example, the program generates two sinusoidal signals, adds them, plays the sound and plots all signals and the spectrum. Figure 2 presents two signals and their sum in time domain. Figure 3 shows the spectrum of the combined signal.

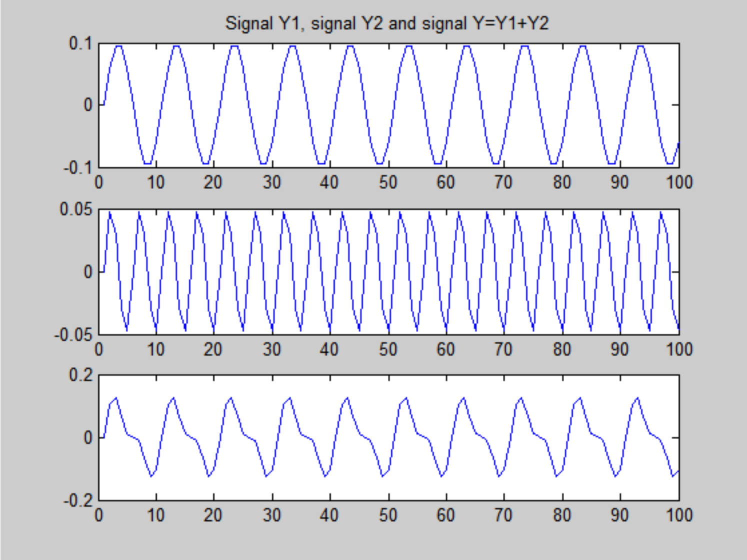

Figure 2: Signal Y1, Signal Y2 and Signal Y as a sum of two sinusoids Y1 and Y2

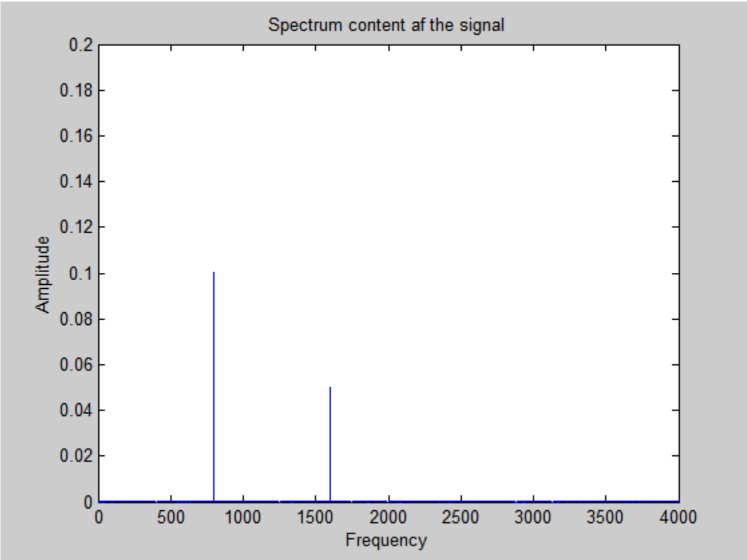

Figure 3: Spectrum of the composite signal Y = Y1 + Y2

Students can easily test theory concepts using MATLAB instead of just doing mathematical exercises.

Practise and application - test for hearing screening

Screening for Hearing Loss

According to Lynn S.A and Washington Sounds (1968), Humphrey, Herbst and Faurgi (1981), and Gallup (1980), there are two populations with hearing problems:

- 30 to 50 percent of the population over 65,
- Young children are usually not detected before the age of 3 to 7.

For children, early detection of hearing problems through screening is very important.
Equipment like FONIX 6500-CX Hearing Aid Test System, are complete hearing analysers.
FONIX provides test sequences for ANSI IEC and JIS standards.
Acoustic drive signal uses frequencies of 100Hz through 8000 Hz in 100 intervals.

Screening is a simple procedure and can be done by non-health professionals.

Having that in mind an assessment task was created. The idea is not to replace a Hearing Aid Test System, but to give students a chance to design an application. Their product can be used to discover possible problems and if so, issue a recommendation to a person to see a medical practitioner.

MATLAB test

After learning how to generate a signal, by doing all of the above, students are ready to do a practical assessment task. The task is part of a bigger project that will follow later.

Digital signal processing project task on generating signals: Screening Test

1) Design a MATLAB program as a tool to test hearing.
2) Produce a report to explain hearing map, and how to use your program.
   Put proper comments in the program, as well as your name and copyright statement.
   Your program should create and print a hearing map that should show: frequencies, in the range of 100Hz to 20KHz, in variable increments and, signal amplitudes needed, for a tested person, to hear the sound.

Assessment Method: Printed report, program and demonstration in the class.
Due date: *A date*
Assessment Criteria:

Program working, only.	PA
Program working, with appropriate comments.	CR
Program working, with appropriate comments and report (1000 words).	DI

Well designed program working, with appropriate comments, and report addressing issues of program design, as well as, issues of hearing (1000 – 1500 words). HD

Possible solution

```
%Matlab screening for hearing loss test
%Tested frequencies are given in the vector fr
      fr = [100 300 500 700 1000 1250 1500 1750 2000 2500 3000 4000 5000
7000 10000 14000 18000 20000];
      Level(1:18)=0;          %vector to hold needed sound level
      fs = 40000;             %sampling frequency
      dur = 2;                %duration of the signal is 2sec
      tt = 0:(1/fs):dur;
%
Choice=1;index=1;
msgbox(' Welcome ');
pause(5)
while Choice == 1,
    i = 1;
    while i<19,     %loop through frequencies given in the fr vector
            M=2;Amp=0.001;          %Amp is tested intensity level
            while ((M == 2)&(Amp<=10))
                Amp = Amp*10; % increase sound intensity
                xx = Amp*sin(2*pi*fr(i)*tt);
                  sound(xx,fs,16);
                M = menu ('Have you heard that?', 'Yes','No','Next');
                      if M==3
                    Amp=10
                    break
                end
```

```
            end
                  Level(i) = Amp          % save the current level
                i = i + 1;
     end
%
        figure(index); semilogy(fr,Level) %log scale(base 10)for Y
        grid on
        ylabel('Sound Intensity Level');
        xlabel('Frequency in Hz');
        title('Hearing Test Report');
        Choice=menu('Would you like to do the test again?','YES ', 'NO');
        index=index+1;
end
%      Copyright © 2002 Dr Milan Simic
```

Figure 4: A simple MATLAB Screening test program

Figures 5, 6 and 7 present hearing maps produced by different programs, for different persons. Sound pressure level should be expressed in dB, but since different PC multimedia devices will produce different outputs, calibration should be done for more accurate results. It was not the intention in the first place. Instead of that, Y-axis represents just amplitude of the signal in a log scale, Figures 6 and 7. Students produce similar figures and show interest in hearing and seeing signals.

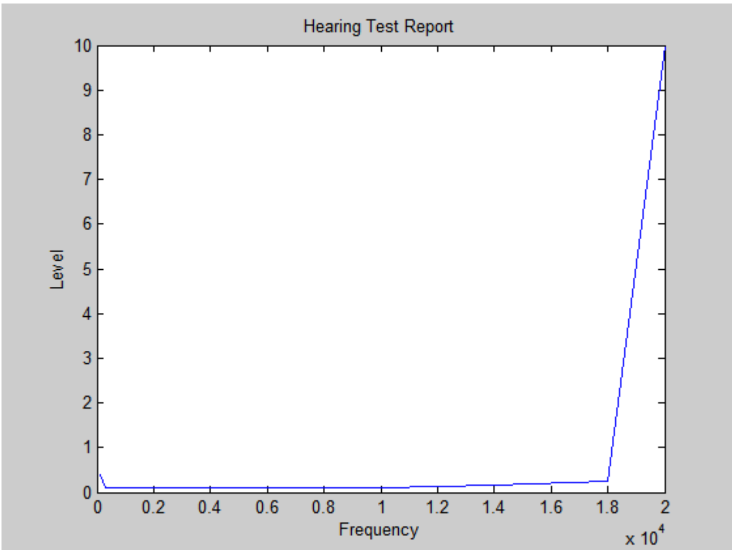

Figure 5: Hearing test report 1, linear axis, increment of amplitude is 0.05

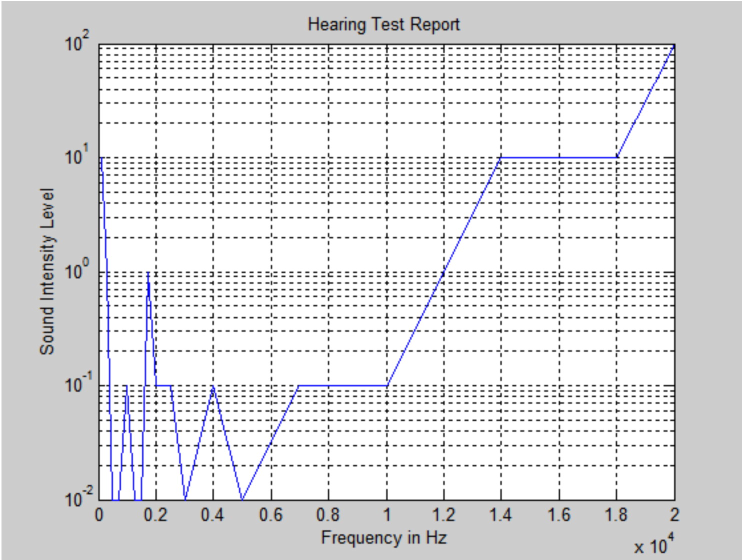

Figure 6: Hearing test report 2 showing some hearing problems

With a slight modification of the given program, Figure 4, we can produce a printed report like one shown in the Figure 8. Intensity of the sound is expressed in dB and frequency is shown in log scale, as expected.

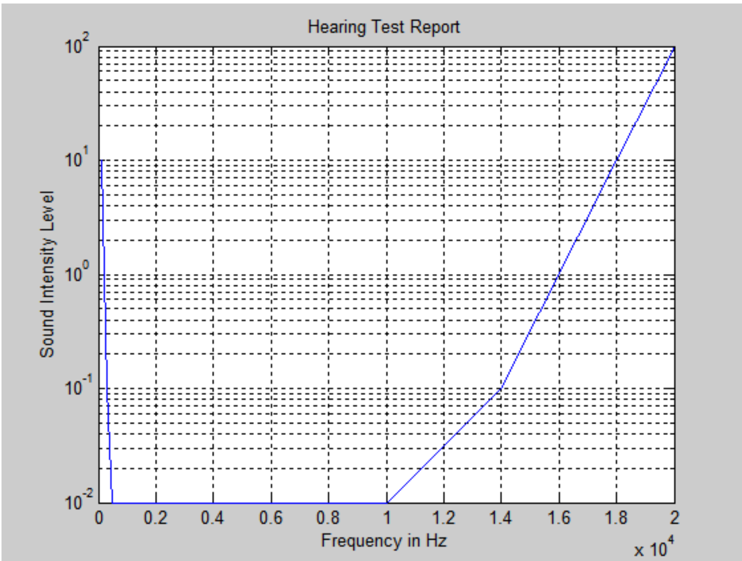

Figure 7: Hearing test report 3, logarithmic scale for amplitude

By asking students to work in teams and demonstrate their product, their ideas, feelings and actions are enforced. As team members, students have their responsibilities; they share ideas, teach and help each other. There is also competition among teams. The project is practical, so that immediacy is in place as well. The roles of the teacher and the student are clear and the role of each team member is usually clear, too. All students are fully engaged in designing and testing their applications. If students are exposed to too much theory and new concepts, they can easily lose interest in the learning process.

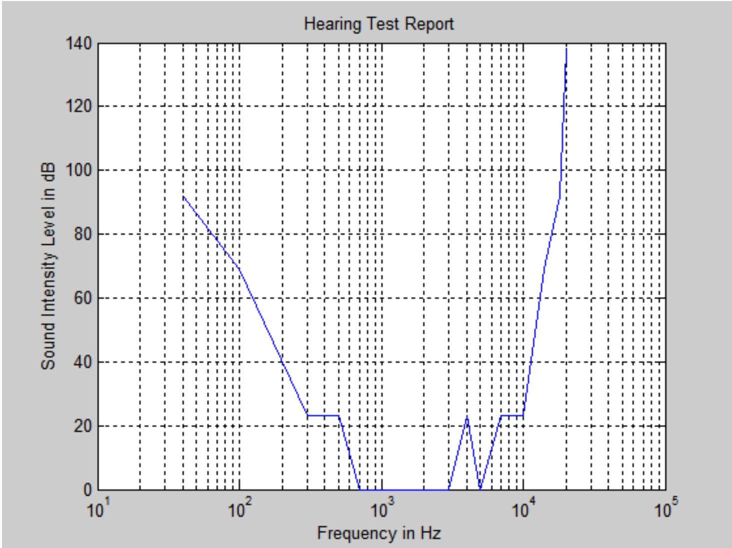

Figure 8: Hearing test report 4, logarithmic scale for amplitude and frequency

MATLAB solution for Fletcher-Munson Equal Loudness Curves

In 1933, two researchers at Bell labs, Fletcher and Munson gathered information about how we perceive different frequencies at different amplitudes. They created "Equal Loudness Contours" or "Fletcher and Munson Curves".

Those curves show as that there is a different threshold of hearing at different frequencies and the apparent levels of equal loudness at different frequencies.

The softest sound that we can hear is equivalent to a pressure variation of 20 µPa, at the frequency of 1kHz, Martin (2002). If we change the frequency we need higher amplitude of the signal.

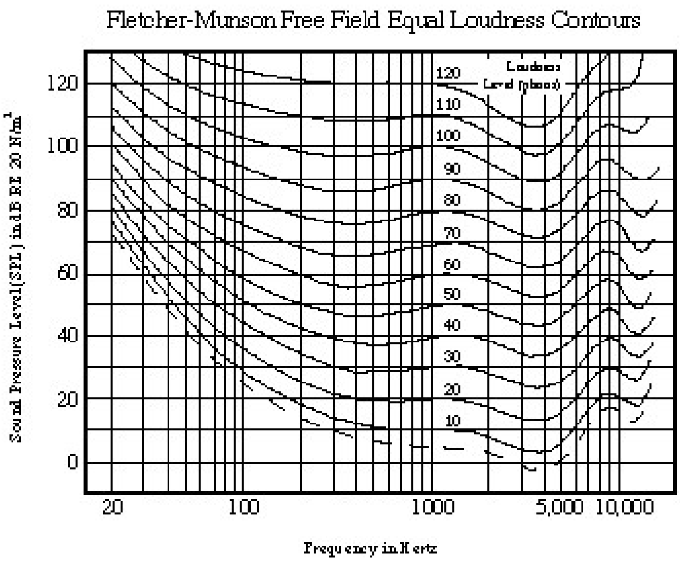

Figure 9: Fletcher-Munson equal loudness curve, from ACS

This forms the basis of another assessment task. Students have to write a program that can be used to draw Fletcher-Munson Equal Loudness Curves.

Processing signals and Deconvolution

After being introduced to FIR Filters, z-Transform, IIR filters, and after learning more about spectrum analysis, students are ready for the final project. The project objective is to design a program that can be used as a hearing aid. Using the aid, a person with hearing problems, such as that given in Figure 6, should be able to hear normally for his/her age, as given in the Figure 7, and generally according to the Fletcher and Munson Curves shown in Figure 9.

The system that includes human ear and a hearing aid, is the LTI (Linear time-invariant) system, as given in equation (6). Input and output are sound signals. The Z-transform of the output, Y(z), is equal to the Z-transform of the input, X(z), multiplied by the system function of the LTI system, H(z).

$$Y(z) = H(z)\, X(z) \tag{6}$$

The human ear is a filter, with the system function $H_e(z)$.
Hearing aid is another filter, with the system function $H_a(z)$.
We have to cascade two systems so that the new system, with the system function $H(z)$, as given in equation (7), will have system function equal to 1.

$$H(z) = H_e(z)\, H_a(z) = 1 \tag{7}$$

In other words, the second filter, which is our hearing aid, has to undo convolution produced by the first filter, the human ear. That process is called deconvolution, or inverse filtering.

Addressing principles and theories of adult learning

By following the approach of Sequence and Reinforcement, described in this paper, I hope to have made it easier for students to learn and apply DSP principles in engineering. By asking students to start designing useful applications, from the very beginning I am applying the principle of praxis. Students can easier understand complex principles by describing, discussing and analysing them. Through designing application, they learn how to implement skills and further enforce the knowledge. By interaction during the course and asking for their evaluation of the course, after, I practise respect for learners as subjects of their own learning. Most of the projects are designed and given to students, so that they have to do the job as team members. As team members, students share responsibility for their own learning. They help each other. Through communication they share skills and achievements. All of these support learning and speed up the learning process. Finally, industry projects are team projects. By being exposed to the teamwork, students are better prepared for the future workplace projects.

Student Feedback

Every year, during and after the course surveys on student satisfaction are conducted. Although the course is hard and heavily loaded with maths, students enjoy it and achieve a lot. Students are asked to comment on aspects of the course such as: are they happy with learning environment, does teacher provide clear instructions and feedback, how diverse are assessment methodologies and do they reflect learning outcomes, is material being presented effectively, and is the material being thought relevant for industry. Grading for each question goes from 1 to 5, 5 being the best. Students are encouraged to add comments.

The survey results given in the Figure 10, show that students are happy with the environment, as the average satisfaction number was 4. They are happy with clear instructions and the feedback, which is very important having in mind that, we are speaking maths language in this course. The survey is just a part of the feedback that is happening in the class, and after the class: consultation time, email… According to the survey, the course is on industry track, with mark 4.16. From the surveys one can always get some ideas how to improve teaching for the future.

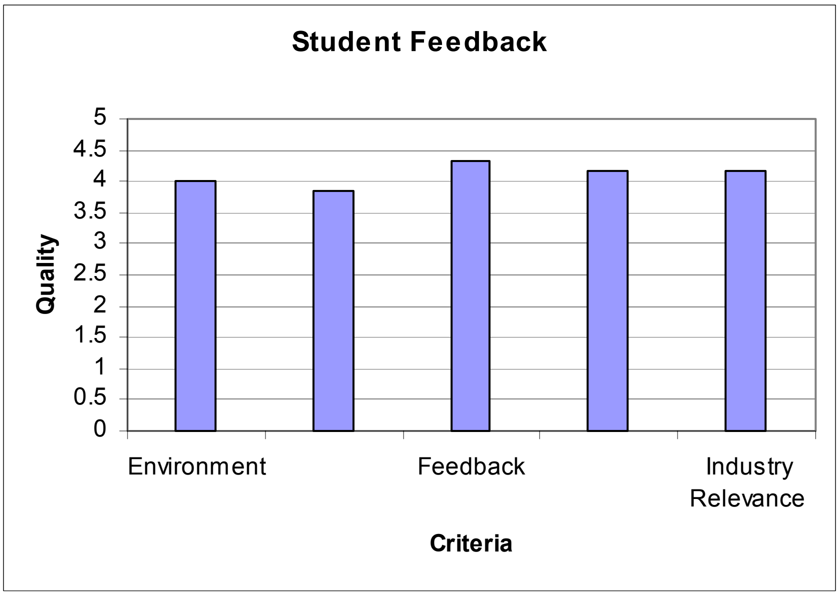

Figure 10: Student Survey Results

Some of the typical comments from the survey are given below.
Student comments about project-based teaching were:

> "I think that hands-on approach supports and reinforced theory. It is a good way to learn".
> "Very good as you get to practice theory and have it in an operating program at the end."

Comments about real understanding the physical concepts underlying DSP by interacting with MATLAB were:

> "Yes as you could visually see and hear the end results."
> "MATLAB is a good tool for manipulating signals. And demonstrate concepts well."

Comments about Sequence and Reinforcement:

> "Yes the more reinforcement given the easier the theory becomes"

A comment about how the given teaching approach is performed:

> "Transferring theory into practice worked well."

Suggestions to improve teaching:

> "More step by step, from basic to difficult."

The subject material of DSP changes and that influences teaching accordingly. Traditionally DSP was taught mainly mathematically and this made it very difficult for students to grasp the physics behind the concepts. This later evolved into teaching DSP via a combination of, maths and FORTRAN, ASM language, C++, C. Currently MATLAB is used to support teaching and industry use it to develop real life applications. This paper has presented a methodological approach for introducing MATLAB into DSP teaching.

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Fletcher-Munson Equal Loudness Curves, from http://www.allchurchsound.com/ACS/edart/fmelc.html

Enhancing Diversity in Engineering as part of an Action Plan – Work in Progress

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Abstract: *This paper explores two strategies in the implementation of a Diversity Action Plan in the Faculty of Engineering. The first strategy is designed to increase diversity awareness amongst the 1st year undergraduate cohort and therefore create a culturally inclusive environment for all student equity groups. The second aims to redress the gender imbalance in academic staff numbers, with a view to attracting more women into engineering by increasing the number of female academic role models. Student feedback on the diversity awareness seminars was positive. The implementation of the second strategy is underway at the time of writing this paper. The strategies, their implementation, expected outcomes and feedback from students and staff are all addressed.*

Keywords: *diversity in engineering, gender imbalance in engineering, transition to university, women in engineering*

Introduction

'Diversity' is recognised as an important aspect and a core value of the culture of the University of Melbourne. The University has acknowledged that it is fair and equitable to promote diversity for the benefit of all its students and staff. Diversity (or cultural diversity) in this context is recognised as encompassing differences due to all of gender, race, ethnicity, language, religion, age, sexuality, disability, belief systems and educational background (The Melbourne University, 1998). Wulf (1998) has discussed the notion of the 'individual diversity' of a person; the sum total of the work (and life) experiences of an individual. He has emphasised that engineering is a creative profession, and it is the diversity of experiences of an engineer that matter, in developing the best solution to a specific engineering problem. Therefore, if diversity in thinking and of people are not utilised, an opportunity cost is incurred in the cost of products not built and designs not considered, etc. Sinclair (1998) has used a similar approach to discuss the 'business case' for managing diversity, and the cost benefits of the effective use of diversity.

This concept becomes critical for an Engineering Faculty with a large gender disparity amongst its academic staff. For example, the proportion of women academics in Engineering (16%) is the lowest of any Faculty at the University of Melbourne. This proportion had remained at 12% for the past couple of years. However, some of the initiatives introduced previously have resulted in the increase that is seen today. Past initiatives have included, the creation of the role of Assistant Dean (Transition & Diversity) and availability of flexible working conditions, such as, working from home, and the availability of part time employment for women retuning from maternity leave.

With the growing push toward internationalisation of the campus, it is also important to promote social harmony, and eliminate all forms of discrimination or harassment toward an individual or group within the student cohort. To a large extent, this can be achieved by education. A study by Lawrence & Male (2001) found that the introduction of a compulsory lecture to 1st year engineering students on rights, responsibilities, equal opportunity, harassment and discrimination markedly increased their awareness and knowledge of these issues.

This paper describes two diversity related initiatives implemented at the University of Melbourne. It is an attempt at correcting the gender disparity amongst academics, and promoting a better understanding of other viewpoints, opinions and perspectives amongst 1st year students; summarised by the maxim "learning requires openness to difference and challenge" (The University of Melbourne, 2002).

Enhancing Diversity – The Action Plan

Current Gender Diversity

Staff

Table 1 shows the academic staff gender profile for the Faculty of Engineering, as at 5th February 2003.

Category	Female	Male	% Female
Teaching & Research and Research (all)	32	174	16
Research only	17	74	19
Teaching & Research only	15	100	13
Teaching & Research (level C & above)	7	77	8
Teaching & Research (continuing)	11	94	10

Table 1: Faculty academic staff gender profile (Faculty of Engineering statistics)

Of a total of 206 academic staff members (Teaching & Research and Research only) only 32 (or 16%) are women. Moreover, there are only a few women at the senior academic levels of Level C and above (7 women compared with 77 men). Of the 7 women, 5 are appointed at Senior Lecturer level and 2 at Associate Professorial level. Furthermore, just 11 Teaching & Research (continuing) positions are held by women, compared with 94 that are held by men.

Currently, there are no female Professors, and in the history of the Faculty there has not been a female Dean. The Head of one department currently is a woman. One other department however, does not have any women amongst their Teaching & Research academic staff.

University wide, there is a better gender balance with 41% of all academic positions held by women. Of these 35% are Teaching and Research positions and 27% are senior positions (Teaching & Research, at Level C and above).

Students

The gender profile for students; undergraduate (current) and postgraduate (2002), as well as, course completions by undergraduate students in 2001 are given in Table 2. Although there has been a steady increase in the percentage of women enrolling in undergraduate and postgraduate engineering programs over the past few years, currently the average female undergraduate student enrolment across all disciplines stands at 25% (the National Indicator for participation of women in engineering being 16%).

Female domestic postgraduate enrolments are slightly better at 28% with a relatively lower figure of 21% for female international postgraduate students.

Specific disciplines within engineering, such as, chemical engineering however, have consistently accounted for much higher female undergraduate enrolments (of nearly 50%) over the past few years. This is thought to be the highest nationally, and higher than the figure reported for chemical engineering in the USA, which is 37% (Dorland, 2003).

The total enrolment of women undergraduates at the university in 2002 was reported to be 57%.

Category	Female	Male	% Female
Undergraduate Domestic Students (all)	727	2179	25
Undergraduate Overseas Students (all)	274	805	25
Undergraduate Domestic Students (1st year)	132	451	23
Undergraduate Overseas Students (1st year)	56	199	22
UG Course Completions, Domestic (2001)	141	487	23
UG Course Completions, International (2001)	50	166	23
Postgraduate Domestic (all, 2002)	70	183	28
Postgraduate International (all, 2002)	45	165	21

Table 2: Undergraduate and Postgraduate student gender profile (Faculty of Engineering statistics)

Diversity by Country of Origin

As in many Engineering Faculties around Australia, undergraduate and postgraduate students in Engineering at The University of Melbourne come from a multitude of different educational and cultural backgrounds. International students alone represent over 55 different countries of origin. The top six countries of origin for students are Malaysia, Indonesia, China, Hong Kong, Singapore and India. Overall, 27% of undergraduates and 45% of postgraduates are internationals.

Equally, the Faculty academics are a very diverse group of people originating from many different parts of the world. For example, in the Department of Electrical and Electronic Engineering alone over 15 different countries are represented. Numbers for other departments are unavailable at this time.

Main Objectives of the Diversity Plan

The Faculty Staff Diversity Committee was formed in 2001 with the aim of providing leadership and consultation, to develop and implement diversity strategies in the Faculty of Engineering. Descriptions of the membership and structure of the committee, and its objectives in 2001 were reported by, Brown & Thomas (2002). The terms of reference and the reporting structure remains the same in 2003; the committee reporting through the Assistant Dean (Transition & Diversity) to the Management & Resources Committee comprising the Dean, Heads of Departments, Assistant Deans and other senior staff of the Faculty. In 2003, the following three overall goals were identified for the Faculty of Engineering (in the context of this paper, refereed to as the Diversity Action plan). To achieve each of these goals a series of strategies were developed.

The overall objectives of the Diversity Action plan were:

1. *To provide a working/learning environment in which women and other equity groups enjoy a sense of respect, understanding and equal opportunity in relation to working/learning conditions, promotions and appointments.*
2. *Increase the number of suitably qualified women applying for academic positions to achieve a better gender balance amongst academics.*
3. *Make available Faculty wide Equal Opportunity for Women in the Workplace and Diversity related data, plans and policies to staff and students.*

A Student Centred Strategy

There were five strategies proposed to assist objective 1 of the Diversity plan. Here, the steps taken for implementing one of these strategies has been described. It involved a student centred strategy targeting undergraduate students in the 1st year of study.

"Educate the new student cohort in principles of diversity, social justice and equal opportunity via the 1st year level transition program to stimulate discussions and promote an understanding of social issues".

The 'culture' of engineering has been recognised as one of the barriers to attracting more female students and those from other equity groups into engineering. Therefore, it was important to highlight the positive aspects of studying and working in a diverse environment. Furthermore, it was considered important to educate students on these issues at the start of their University career, at the 1st year level.

With this in mind, one seminar in the 'school to university' transition program was dedicated to introducing students to principles of diversity, social justice, equal opportunity and to their rights and responsibilities.

The School to University Transition Program (ENG101)

The new 'school to university' transition seminar program was developed and offered to all engineering students in semester 1, 2003. Over a 5-week period (1x1 hour seminar every week) this program introduced a series of individual topics or ideas to assist students with the transition to university. Students worked in groups thereby enhancing or developing certain generic skills, such as teamwork skills, oral communication skills and networking skills.

Enrolment in these seminars was optional but strongly encouraged, by having sessions timetabled into all individual student timetables. As there were over 800 students in the 1st year of study, seminars were repeated six times every week. The seminars were held in a large drawing office capable of accommodating up to 150 students. The tables were arranged for groups of 10 to12 students.

The following topics were offered:
Week 1: Getting to know the University,
Week 2: Diversity, Rights & Responsibilities,
Week 3: Academic Values & Teaching Goals,
Week 4: Effective Study & Resources, and
Week 5: Continuing Success.

In parallel to these seminars students participated in a 'scavenger hunt' in the form of a photo safari. The purpose of the scavenger hunt was for new students to get to know some of the interesting people, places and myths of the University of Melbourne.

Week 2: Diversity, Rights & Responsibilities

This seminar was in four parts as follows.

1. Introduction by a senior academic of the Faculty. Presentations included, personal perspectives on diversity, the development of the Melbourne University Cultural Diversity Policy (1998) and the business case for diversity.
2. "Stories to tell" by two students from different equity groups. For example, international and country students, both female and male, provided insights into some of their own work and life experiences during 1st year of university.
3. Three video clips depicting role-play of different university teaching scenarios, with situations of harassment, discrimination or inappropriate behaviour, were shown to students. These scenarios were selected from a video produced by Curtin University of Technology. The three scenarios depicted the following situations:
   i) "*Two students from an English as a first language background are meeting with a lecturer. They are concerned they will be disadvantaged writing up and presenting a report as two other members of their group are from an English as a second language background"*;
   ii) "*Two students are in a lab working together, but one student is not confident that she has followed correct experimental procedure and requests the help of the tutor. The tutor ignores the request and the second student declares he knows the correct procedure and suggests the other student takes notes"*; and,
   iii) "*Drunk male students at a bar-be-que notices two women walking past and calls out in an inappropriate manner"*.

   This part of the session was facilitated with the assistance of University Equal Opportunity Officers. After the screening each scenario, discussion (firstly, within groups and then with the whole class) was encouraged and promoted by asking questions such as:
   - What issues does this scenario raise?
   - What do you feel about this situation?
   - If this happened to you, what would you do?
   - How could this situation be resolved?
   - What do think will happen if the conflict is not resolved?
4. The program concluded with University Anti-discrimination Advisers giving a brief outline of the ADA's role, the resources available, and the complaints procedure.

Objectives and Outcomes of (week 2) Seminar

As well as increasing the knowledge of specific topics covered during the seminar, other aims of this seminar were to provide a forum for students from the different engineering disciplines to meet and make new friendships. It was hoped that interactions between students, both domestic and international, would improve understanding and promote a sense of community within the student cohort. It was also hoped that, instructing students on their rights and responsibilities, would help to avoid situations similar to those shown on the video clips or improve potential outcomes if such incidences did occur, in future.

Evaluation

The students were required to evaluate each seminar at the end of the Transition program. Preliminary results form the student evaluations will be presented in the section on feedback.

A Staff Centred Strategy

There were three strategies proposed to assist objective 2 of the Diversity Action Plan. Here, the steps taken for implementing one of these strategies has been described

"Recruit three full time (or equivalent part time) women candidates with excellent research/industry track records into three (3-year) Faculty funded Postdoctoral Fellowships".

The recommendation by the Staff Diversity Committee to offer three Research Fellow positions to women candidates has been reported previously by Brown and Thomas (2002). Consequently, with the approval of the Management and Resources Committee, this recommendation was incorporated into the Faculty Operational Plan in 2003. Faculty funding for three years at Research Fellow Grade 2 level was approved for all three positions.

These positions are yet to be advertised. Applications will be sought from outstanding women candidates from any field of engineering and selection will be based on a range of criteria including, an ability to work in one of the strategic research areas of a department or research centre, a demonstrated research track record, and experience in working on industry funded research projects. In particular, selection for these positions will be based on a candidate's potential to work in an established area of research of a department or research centre, so that mentoring and collegial support can be offered to candidates by more senior staff. This will provide opportunities for collaborative work on well-funded areas of research with possibilities for higher research output and greater number of research publications.

The women who take up these positions will be offered other career development opportunities, such as, teaching in undergraduate or graduate programs within departments (comprising not more than 20% of their time). It is hoped that these appointments will provide a career path for women to become Teaching and Research academics. Following a favourable evaluation at the end of the first three years, the Research Fellowships will be either extended for a further period or the candidates will be considered for Lecturer or Senior Lecturer positions within departments as openings arise. By providing a clearly defined career path, these Fellows will be awarded tenure and eventually promoted to the ranks of Associate Professor and above.

The expectation is that, the appointment of three academic women would have an immediate positive influence on the 'culture' of the Faculty of Engineering. Moreover, these Fellows will provide role models for female undergraduate and postgraduate students and encourage more qualified women to consider a career in academia.

This would also be in line with one of the University's Performance Targets of improving the percentage of women in traditionally under-represented areas, such as engineering, and would draw attention to the community at large, the importance the Faculty places on improving the gender balance amongst academics.

(To advertise these special positions for only women, the Faculty has applied to the Victorian Civil and Administrative Tribunal for an exemption under the Equal Opportunity Act).

Expected Outcomes

As well as increase the number of female academics in the Faculty, it is hoped that this incentive would encourage more female students to consider careers in academia rather than in industry. These new positions are also expected to contribute towards attracting more female students and students from other under-represented groups into engineering. In the long term it is hoped that this would lead to more women in senior and continuing positions, and contribute to creating an academic environment that is inclusive of all equity groups.

Feedback on the Transition Seminar

Participation

Participation levels by students remained high with nearly 75% of the students allocated to each seminar actually in attendance. Overall, 624 students attended the (six) seminars on Diversity, Rights and Responsibilities.

As there were six sessions of each seminar, it also required the participation of several engineering academics. In all, six academics from various disciplines of engineering were in charge of running the different sessions. Their main role during the seminars was one of facilitation, as EO officers, Anti-discrimination advisers, guest speakers and later year students were involved in presenting and discussing (with students) the relevant material.

Many of the staff involved have so far given positive feedback on the participation of students, and have rated as high the interest shown by many students during the sessions.

The Evaluation Process

Evaluation was carried out at the close of the program in week 5, and in total 224 students returned the completed evaluation questionnaires.

The evaluation questionnaire included the following statements in relation to the seminar.

Statement 1: The content of the session was relevant to me

Statement 2: The information was covered in sufficient depth

Statement 3: Overall, the session met my expectations

Statement 4: The session provided opportunities to meet other students

Students were required to give a rating of 1 to 5 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 = strongly agree) for each statement. The responses to each of these statements are shown in Figures 1 to 4.

Feedback Results and Discussion

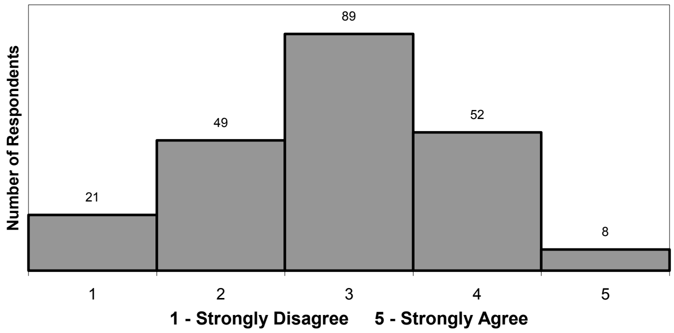

Figure 1: Feedback on relevance of seminar (# 1)

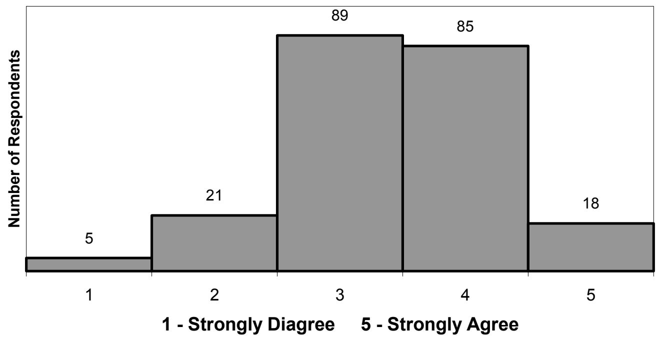

Figure 2: Feedback on sufficient depth of seminar (# 2)

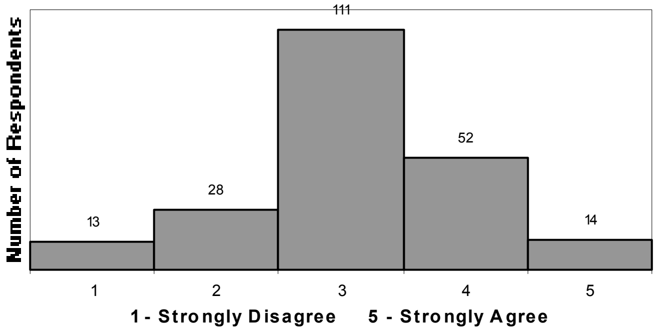

Figure 3: Feedback on expectation (# 3)

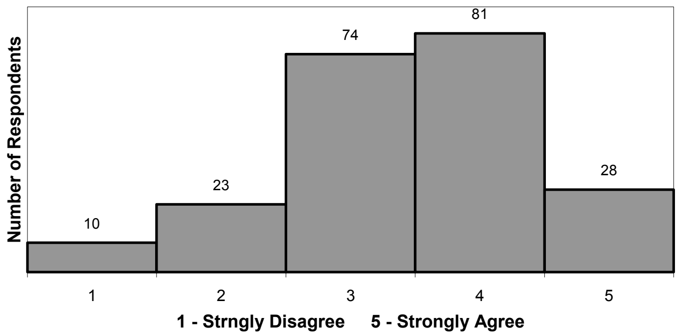

Figure 4: Feedback on opportunities for networking (# 4)

As expected the results show a normal distribution with respect to the ratings of each statement. Specifically the results show that only 12% thought the material was not covered in sufficient depth (a rating of 1 or 2 for statement 2) and 19% reported that the seminar did not meet their expectations (a rating of 1 or 2 for statement 3).

However, 32% said the material was not relevant to them (a rating of 1 or 2 to statement 1) with only 27% agreeing and strongly agreeing that the material was relevant (a rating of 4 or 5). This was contrary to the lively debate and discussion that was noted during most of these seminars. There was overall agreement with statement 4, with 85% of the students believing that the seminars created a good forum for meeting other students.

In response to a question referring to the entire program, "would you recommend this program to someone else?" the answer was positive, with 84% of respondents saying they would.

Comments made by students at the end of seminars indicated that they found the presentations made by staff and students to be very useful. For example, the 'stories to tell' section was reported to be particularly useful by some international students

The feedback results represent 36% of all students who participated in the seminars. To increase the level of feedback, it is expected that all future evaluations would be carried out immediately following the seminar, and not at the end of the program.

Conclusions

Two initiatives have been put in place in the Faculty of Engineering, University of Melbourne. Both these initiatives were part of an overall Diversity Action plan to enhance gender diversity amongst staff and increase diversity awareness amongst students.

A seminar on Diversity, Rights and Responsibilities was offered as part of the School to University transition program in the Faculty of Engineering. Well over 600 1st year students attended this seminar, and took part in discussions of the various topics raised during the session. Feedback from students and staff has been positive, with most students indicating the seminars met their expectations and that the material was covered in sufficient depth. The evaluations also showed that the sessions were a good forum for students of different cultural backgrounds and different engineering disciplines to meet, providing opportunities for networking and making friends.

The second initiative aimed at increasing the gender diversity amongst Faculty academics, involved the establishment of three (3 year) Research Fellow positions for women candidates (yet to be awarded). These positions will encompass the possibility of articulation into Research and Teaching positions and is expected to attract outstanding women candidates interested in establishing careers in academia, in the long term.

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Acknowledgements

The authors gratefully acknowledge the contributions made by the staff of the Equal Opportunity and Equity & Learning Programs Units, Anti-discrimination Advisers at the University of Melbourne, members of the Faculty of Engineering Staff Diversity Committee, past and present, and the academics who worked on the 2003 ENG 101 Transition Program.

The authors would also like to thank Ms Sally Male of Curtin University of Technology for permission to use parts of the video on harassment and discrimination, and ESSO-Mobil Australia for a grant of $10,000 in support of the Transition Program.

Women in engineering - an innovative model enhancing diversity

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Abstract: *This paper presents an overview of an educational innovation at RMIT University - the Engineering Awareness Program for Girls (EAP).*

In the opening sections this paper discusses the pedagogical approach adopted in the EAP and considers how the EAP is effective in addressing low levels of access and participation in Engineering Programs. Specifically, consideration is given to how some of barriers, which prevent females from entering the engineering profession, are challenged and overcome.

We present the EAP as a successful strategy to attract more young women to study engineering and as an innovative community partnership model, which enhances graduate capabilities. This paper examines the factors, which influenced the original design and development of the EAP, considering both implementation and the factors, which determine sustainability through a cross-sectoral partnership approach.

Recommendations for the future are discussed in the context of examples from similar, successful programs offered overseas and in the context of RMIT's Teaching and Learning Strategy. More broadly, the EAP is discussed in light of RMIT's Mission to promote lifelong learning, innovation and community partnership building.

Keywords: *Graduate capabilities, Access and Equity in Engineering- supporting women in engineering, community engagement- RMIT University and local learning communities.*

Introduction

Since it's inception in 1997, the Engineering Awareness Program for Year 10 girls (EAP) has provided an innovative response to the under representation of women in the engineering profession. In 1983 approximately 5% of engineering graduates were women, a figure that only increased to 15% by 2000, (Lee, 2002). In Australia only 6% of practicing professional engineers are women, (Lee, 2002) In the case of RMIT, only 5% of engineering undergraduates were women in 1986. Over the past 15 years this has increased to 17% in 2001. In the VET sector, however, only 4% of engineering students at RMIT are currently women (RMIT Engineering Equity Unit, 2002).

The EAP provides an effective and innovative response to this gender imbalance and to date 240 students have participated in the program. The EAP targets girls in the middle school years, just prior to them making subject selections for the Victorian Certificate of Education, which will determine tertiary study choice. The EAP runs over two days between two and four times per year. The aim is for the program to take place before students make their final choices for VCE subjects, usually prior to October. Most of the sessions and workshops take place at the RMIT city campus, with one workshop at the Fisherman's Bend campus where Aerospace Engineering is offered.

The EAP for Year 10 Girls has for the past five years been a cooperative effort between the Equity Unit, Faculty of Engineering and CIECAP. CIECAP supports schools across Melbourne, and a key part of its focus is to enhance teaching and learning in science and technology and technology education. It is a division of RMIT's Community and Regional Partnerships in the School of Enterprise and Community Partnerships. The University's support for CIECAP and the projects it undertakes, such as EAP, is part of its broader commitment to Community and Regional Partnerships.

Program Design

The EAP provides Year 10 girls with the opportunity to participate in an interactive forum over two consecutive days and consists of the following:

Role Models: Presentations and informal discussions with female engineering students and female undergraduates currently working in the engineering industry. Speakers provide a snapshot of their lives, including influences they have had and obstacles they have overcome.

Informal discussions: Aimed at challenging some of the stereotypes, which underpin student's perceptions of the engineering profession

Information sessions; Student Recruitment provides an introduction to RMIT while the Careers Centre provides information and advice regarding various programs offered.

Hands on workshops: Activates offered in the workshops are developed by teaching staff from various departments. These are hands on and result in the student making something that they can take home, such as a CD holder or an aeroplane

Benefits

Female Secondary Students

Secondary students are given the opportunity to work with technologies not available to them in their schools and to experience a unique learning environment as they work with girls from a range of schools with whom they share common interests. The EAP encourages school students to develop problem-solving strategies, encouraging prediction, inquiry and reflective practice. Activities are designed to enable school students to understand the connections between each specific workshop and the skills and thought processes employed by engineers working in the profession, and to gain an insight into the diverse nature of the profession.

The EAP responds to the well-researched need to provide students with the opportunity to engage with the world outside institution or school, noted as a major issue at the first Global Conference on Lifelong Learning in 1996. By meeting with RMIT Alumni and undergraduates, the engineering profession is demystified as young female engineers relate personal stories about their own study and career paths, reflecting on obstacles they have encountered and how these difficulties have been overcome. Further, school students are able to make connections between their own schooling and the worlds of further education and work. In reflecting on the EAP program, school students are encouraged to see how their feedback informs future program development. They are encouraged to share a commitment to inform their own communities about the diverse nature of the profession, and to challenge the stereotypes, which impose barriers to women entering the field of engineering.

Graduate Capabilities

Through participating in the Engineering Awareness Program, both young women in industry and RMIT undergraduates and postgraduates are encouraged to see themselves as significant and positive role models for female secondary students. The EAP encourages RMIT students and Alumni to see their role as engineers as one that supports diversity in the engineering profession by encouraging potential female engineers. This program enables undergraduates and Alumni to contextualise their own learning and work, and to understand and value lifelong learning and access for all. Further, the EAP fosters leadership skills, enhancing presentation and communication skills, supporting work readiness and career long learning. In reflecting on their own career and study choices, women develop a deeper understanding of their potential and capacity to make an invaluable contribution to the engineering profession and to society in general. The EAP provides RMIT female undergraduates with the opportunity to develop their leadership through contributing to the community in ways which `develop RMIT students to be knowledgeable, creative, critical, responsible and employable, as well as being life-long learners and potential leaders′ (RMIT Strategic Plan, 2000 to 2004.)

RMIT Teaching Staff

Through practical involvement in the EAP, RMIT lecturers and tutors become more aware of equity issues and of their relevance to current and prospective students. Staff are given the opportunity to reflect on their own academic development.

Continual Improvement

The EAP Programs form part of a continuing cycle of teacher and student evaluation, reflective practice and continued improvement in program design and delivery, ensuring that learning is relevant and responsive to students needs, providing the opportunity for students to pursue learning congruent with their interests. Programs are continually reshaped and developed as knowledge is integrated across disciplines and learning communities, and applied to the changing and emerging educational needs of students, both internal and external.

Women in Engineering

While women had long been under represented in higher education, this has remained particularly so in the field of engineering compared with other disciplines. As previously noted, very few women had studied engineering at Australian universities until quite recently.

The Williams ‘Review of the Discipline of Engineering’ was undertaken in 1988 and recommended that steps be taken to increase the number of female graduates (Bellis and Armstrong 1998, p. 27). Since then, many universities have addressed the issue by offering programs aimed at attracting girls into undergraduate engineering studies.

Strategies to encourage young women to study engineering

In Victorian universities, a number of strategies are being used to attempt to address gender imbalances in the engineering profession and encourage young women to consider engineering as a viable career option. Most engineering Faculties visit secondary schools to offer information sessions for both students and parents. Speakers at these sessions range from Faculty staff members and students to graduates from industry. Newsletters and a range of relevant career information are also regularly provided to students in a variety of formats including CD-rom, via their careers teachers.

The EAP program is particularly innovative, having the following unique elements:

- Offers workshops in a variety of departments across the Faculty of Engineering (FoE)
- Runs over two consecutive days providing the opportunity for secondary students to be immersed in university life as well as the world of engineering
- Provides additional activities involving female engineering students and representatives from industry
- Focuses solely on Year 10 students who are ready to make subject selections for VCE
- Brings together students with similar interests from a variety of schools
- Targets students from non-English speaking and disadvantaged backgrounds.
- Provides female students with the opportunity to access opportunities and refine knowledge about pathways and career opportunities
- Creates opportunities for secondary students to work with current technologies not available to them in their school
- Provides opportunities for young women to pursue areas of interest where they are motivated

It is worth noting that other programs such as Mentoring Programs are offered at most institutions, including RMIT, to ensure that the academic experience of students who do go on to study Engineering is positive and successful.

Research

In light of the Williams Report, (1988) and qualitative and quantitative studies undertaken at RMIT, it was clear that new programs needed to be implemented if more girls were to consider pursuing an engineering education.

Possible practices being offered in Australia and overseas were considered. By this time over half of university engineering departments reported that they had implemented some kind of special "Women in Engineering" program (Bellis & Armstrong, 1998 p. 27). While a range of strategies had been used, evidence suggested that intense, hands-on, on-campus initiatives were the most effective in motivating young women to undertake studies in engineering (Hiscocks & Zywno, p.4). A vision was shared by staff from the Faculty of Engineering (FoE) and Community and Regional Partnerships, that this type of program would have positive outcomes.

Implementation of the Engineering Awareness Program

The EAP was first adopted in 1997 and has been implemented on an annual basis since that time. RMIT teaching staff are encouraged to participate in the program. The following discipline areas within the Faculty of Engineering were invited to participate in last years EAP.

- Chemical Engineering (HE)
- Computer Systems Engineering (HE)
- Aerospace (HE)
- Training Centre for Telecommunications (VET)
- Computing and Electronics (HE)

Gaining assistance from engineering students and industry representatives

TAFE, undergraduate and postgraduate engineering students are invited to become involved in the EAP. Student Recruitment is involved in identifying appropriate students and gaining their support. In addition, female graduates employed in the engineering profession also participate. This is mainly organised through RMIT Alumni, and includes past students who have been recipients of equity scholarships and those who have been involved in industry work placements as part of their degrees.

Selection of participating schools and students

Initially, schools are selected for involvement in the program on the following basis:

- Utilising the data base of schools which CIECAP regularly works with on a range of projects, based largely in the inner city region
- These schools have initially been selected in line with the CIECAP brief of meeting gender and equity targets, in response to socio-economic disadvantage and cultural diversity
- Sustainable partnerships have been built with particular school communities and their Careers Advisers, with regular visits to these schools by CIECAP staff.

Letters are forwarded to participating schools outlining the rationale for the program and informing principals and careers advisers of the curriculum to be offered. For many of the schools who have previously been involved this is to renew partnerships and reinforce their understanding of the EAP.
These schools are invited to select between four and six students who will partake in the program. RMIT do not specify any criteria in relation to student selection; this is determined entirely by the school.

The method used to select participating students varies from one school to another. Schools will generally market the program through a feature in their newsletter, and girls who have previously participated may be asked to speak about their experience to Year 10 Girls. The school will then await feedback from interested girls.

Other schools will selectively offer the program to girls who have displayed an aptitude for academic subjects required to do further study in engineering. Girls interested in the program generally remain open about their career choice, or may have expressed interest in the engineering profession.

Teaching Approach

The EAP employs a range of teaching strategies, adopting a student-centred approach, and encourage reflective practice for both teachers and learners. A significant component of the EAP is the provision of a mentoring/peer tutoring approach - a well researched and widely acknowledged means of effectively engaging young people. The teaching approach underpinning the EAP fosters inquiry, discovery, and problem solving modelled through question and presentation skills, providing opportunities for students to develop creative solutions to problems. Experiential learning forms a key part of all EAP programs as secondary students engage in a range of hands on interactive workshops. These teaching strategies enable all students to contextualise their own learning and this in turn develops a framework by which students can establish and identify the relevance of learning beyond their own learning community. Notably, learning is facilitated as a connected whole, rather than as a series of unconnected activities.

Measuring the success of the EAP

Basic quantitative and qualitative research conducted by CIECAP staff throughout 2001/02 indicated the following outcomes:

- Approximately 40% of the students who participated in the first EAP in 1997 were enrolled in engineering courses in 2001
- 75% of students from the 1998 EAP had included engineering in their top three VTAC preferences for study in 2002
- The five students from one school who had attended in EAP in 1999 had listed the following courses as their first preference for university entrance:
    - Engineering/Commerce
    - Commerce/Information Systems
    - Science/Engineering
    - Software Engineering
    - Forensic Science
- One school indicated that 100% of students who attended the EAP in 2000 had enrolled to study physics in their VCE.
- One school reported that the majority of their Year 12 graduates entered tertiary courses at RMIT in preference to alternative universities.
- Students who participate in the EAP often influence others when they return to school. At one school 40% of students who did **not** participate (due to lack of available places in the program) went on to enrol in engineering courses.

- Teachers and careers advisers from secondary schools involved in the program have expressed their on-going commitment to the program and requested additional programs to cater for a greater number of students.

These outcomes are considered to be positive and successful by both CIECAP and the RMIT Equity Unit.

Other Innovations

Briefly, other innovative practices with the objective of increasing the number of girls pursuing a career in engineering include:

- Universities collaborating with secondary school educators by developing curriculum modules which highlight the design process central to all aspects of engineering to be incorporated into science, maths and technology classes (Raytheon/University of Massachusetts K-16 Engineering Collaboration, p. 1).
- Engineering Curriculum developed and presented in schools by female role models (Women in Engineering Programs & Advocates Network).
- Parents involved as support mechanisms for their daughters, including educational workshops for parents (Project 1999: Partnership in Recruitment of Anglo/Minority Girls into Engineering)
- Tours of industrial sites (Project 1999: Partnership in Recruitment of Anglo/Minority Girls into Engineering, 1999)
- Professional bodies taking a leading role in funding and designing programs and activities that will encourage girls to study engineering. For example, The Society of Manufacturing Engineers Education Foundation (based in the US with members from seventy countries) has provided considerable funding to one such program since 1998. The STEPS (Science Technology and Engineering Preview Summer Camp for Girls) is a tuition-free, residential program held across six colleges/universities (SME Education Foundation). This is a national initiative, which aims to grow to cover eleven states reaching 36,000 girls (STEPS).
- Universities in Alberta Canada have come together to establish a science and engineering email mentoring program aimed at girls between 11 – 18 years of age. The program matches these girls with female science and engineering students and women practicing as scientists and engineers. Participating girls are provided with knowledge and motivation from role models through an opportunity to communicate with mentors in a field where there are low levels of naturally occurring mentoring relationships (Scriber Mentor).

Access and Equity

In this context we understand the EAP to be an intervention into the discursive practices of engineering, and while programs such as EAP are not the sole agents of change, the notion of a 'community of practice' engendered through participation in the EAP enables discursive changes.

The notion of a community of practices sees the EAP not just as the exposure of girls to a set of experiences otherwise not widely available, but instead as a chance for negotiation and creation of learning experiences, of assumptions, of paradigms that inform identity. In this way of looking at the EAP, the girls, the academics and teaching staff, the facilitators, postgraduates and the alumni are all practitioners in the creation of a set of possibilities in engineering practice.

By situating the EAP within a Teaching & Learning framework, and by using the model of communities of practice to encourage reflection the EAP becomes a vehicle for exploring the possibilities of engineering activities and identities. We believe that this contributes to the growth and development of engineering discourse, and ultimately of more equitable and sustainable engineering practice.

Recommendations

- That the EAP be aligned with Teaching and Learning and that the EAP program is developed as an elective for undergraduates programs, thus ensuring that the EAP articulates directly to Teaching and Learning across the curriculum, maximising the programs potential to enhance graduate capabilities

- That the EAP continues to target students from socially and economically disadvantaged backgrounds as target equity groups

- That partnerships between industry and the EAP be developed with a view to seeking corporate sponsorship for the Program – this would be done in conjunction with RMIT Development. If sponsorship was forthcoming the number of Programs could increase, the free show bags could include a wider and more appealing range of promotional material, and industry could have a more hands-on role in the development of the EAP in the future.

- That the Engineering Awareness Program continue to respond to feedback from participants in expanding the component of interactive workshops offered in the program

- That we investigate ways of integrating the EAP with the Engineering Mentor Program by using existing student mentors as on-line contact people who may also be willing to visit the schools to talk about engineering

- That the Equity Unit maintain ongoing contact throughout Years 11 & 12 with each of the EAP participants eg by sending information on scholarships, the WIE magazine, Open Day information etc

- That the profile of the EAP is lifted both within RMIT and the wider community, including through partnerships with other universities

Conclusion

While the under representation of women in engineering remains a concern, hands-on, on-campus programs such as the EAP have proven effective in motivating young women to consider this field. The experiences of the EAP in its early years has demonstrated that there are many girls prepared to consider engineering careers given the necessary exposure and encouragement that such programs can provide. In working with young women prior to them entering their post compulsory schooling, the EAP is active in the years when young people are developing their identities as learners and making critical choices that will influence their future study and career pathways.

Further, the EAP provides a model of community engagement, building links between the university and local learning communities. Such community partnerships are sustained by mutual trust and respect and a shared vision of enhancing and supporting diversity in the engineering profession through addressing the current gender imbalance. Through such an innovative partnership model, the barriers which undermine access to learning are challenged, as are the stereotypes which surround the engineering profession. The EAP is effective in encouraging our potential female engineers of the future whilst it successfully enhances the capabilities of our female engineers and female undergraduates of today.

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On the popularity of engineering among Brisbane high school girls

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Abstract: *The main objective of this study was to measure the interest high school girls have in pursuing a career in engineering, and correlate this interest to the beliefs held by these girls, as well as their family and friends, with respect to women in engineering. A questionnaire was distributed to 92 year 11 and year 12 girls, at Stuartholme School, in Brisbane. The girls were Maths B and Maths C students, and had the required mathematical skills to pursue a career in engineering. Also, as Stuartholme School is a girls-only school, these girls were not exposed to male competition, which has been found to undermine girls' self-efficacy beliefs with respect to pursuing a career in a male orientated profession. The results showed that none of the girls who were already decided about their career path were planning a career in engineering. The results also showed that only a small minority of those still undecided about their career were interested in engineering. It was also found that this lack of interest couldn't be attributed to any negative beliefs about women in engineering, as most of the girls (as well as their family and friends) didn't believe that women engineers were any different from other women, or that the profession of engineering should be restricted to the male population. However, it was found that the girls lacked exposure to female role models, which could explain their lack of interest.*

Keywords: *women, engineering, popularity*

Introduction

Women still constitute a minority in the engineering profession. Despite efforts from equal opportunity programs, the engineering profession attracts significantly smaller numbers of women than other traditionally male orientated professions. Several reasons exist for these unsuccessful attempts to increase the involvement of women in engineering. Firstly, high school boys seem to display higher problem solving skills and visual-spatial abilities than high school girls (Meinholdt, 1999). Secondly, several studies seem to attribute girl's lack of interest in science and engineering to their self-efficacy beliefs (Meinholdt, 1999; Lapin Zeldin & Pajares, 2000; Heyman, Bryn & Sangeeta, 2002; Mazen & Lemkau, 1990). High school girls seem to doubt more than boys their ability to succeed in mathematically oriented programs and professions, particularly when constantly outperformed by boys in mathematics and science subjects. However, a study carried out in (Blaisdell, 1998) failed to confirm this theory. Thirdly, girls lack female role models, (Blaisdell, 1998) and, as a result, tend to associate the engineering profession with a male only environment.

This study aims to investigate the level of interest high school girls, enrolled in a girls-only school, and with the required level of mathematical skills, show in the engineering profession. It also attempts to correlate their level of interest to their knowledge about the engineering profession, their social beliefs about women in engineering, and their level of exposure to female engineers.

Method

Participants

The sample comprised 92 high school girls from a girls-only Brisbane school, StuartHolme. The participants were year 11 and year12 girls, and were enrolled in Maths B and Maths C subjects, i.e, had the mathematical prerequisites required for undertaking engineering studies and becoming professional engineers. Also, being in a girls-only school, these girls did not have the opportunity to compare their mathematical skills or visual-spatial abilities with other boys. It is therefore assumed that their confidence in undertaking mathematics or science oriented professions would not have been undermined by boys' performance.

Measures

A questionnaire, designed to measure the girls' level of interest in engineering, was distributed to the participants. The questionnaire was kept short following instructions from the Maths teacher. It consisted of fourteen questions. The first two questions targeted the girls' knowledge about the engineering profession. In question three, the girls were specifically asked if they wanted to pursue a career in engineering. Question four was designed to measure the level of opposition family and friends had towards their girl becoming an engineer. Questions five to twelve were designed to investigate social beliefs about women in engineering. The basis for the questions was to investigate whether the girls, as well as their family and friends, carried any preconceived ideas about a stereotype of women engineers, or about social consequences of becoming an engineer. Question thirteen was designed to investigate the girls' level of exposure to women in engineering, and the last question was on the career path they intended to pursue. The format of the first twelve questions followed the Likert scale (strongly disagree, disagree, neutral, agree and strongly agree). In question thirteen, the girls were asked if they knew at least one woman engineer, and, in case they did, were asked to specify where they met them. In the last question, the girls were asked if they knew which career path(s) they were interested in following, and, in case they did, to specify their preferred career path.

Procedure

A questionnaire was sent the StuartHolme Maths teacher, with instructions to distribute the questionnaire to his Maths B and Maths C students. The teacher wouldn't allow me to come to his class as he was on a tight schedule. The girls were instructed to take the questionnaire home, answer it and take it back to their teacher. All girls returned the questionnaire, i.e. the response rate was 100%. The teacher mailed the questionnaires back to me a week after they were sent. Confidentiality was respected.

Results

Interest in engineering

From question 14, it appeared that 53% of the surveyed girls were still undecided about their career path. Answers to question 3 further revealed that, among those 53%, only 8% showed an interest in engineering, while 78% were not interested and 14% were neutral. Among the 47% who knew which career path(s) they wanted to pursue, only 4% replied they were interested in engineering, against 82% not interested and 14% neutral. Among these 47%, 51% were interested in a career in health, 12% in arts, 9% in business and/or law and 9% in science. 19% expressed interest in various other careers such as architecture, police or journalism. Interestingly, the 4% who were seemingly interested in engineering didn't mention engineering as a possible career path. These results are summarized in table 1 below.

<table>
<tr><th colspan="3">Undecided about their career path (53%)</th><th colspan="5">Know their preferred career path (47%)</th></tr>
<tr><td>Not interested in a career in engineering</td><td>Neutral</td><td>Interested in a career in engineering</td><td colspan="2">Not interested in a career in engineering</td><td>Neutral</td><td colspan="2">interested in a career in engineering</td></tr>
<tr><td>78%</td><td>14%</td><td>8%</td><td colspan="2">78%</td><td>14%</td><td colspan="2">8%</td></tr>
<tr><td colspan="3" rowspan="2"></td><td>Health</td><td>Arts</td><td>Business/ Law</td><td>Science</td><td>Other (no engineering)</td></tr>
<tr><td>51%</td><td>12%</td><td>9%</td><td>9%</td><td>19%</td></tr>
</table>

Table 1: Possible career path

Knowledge about engineering

59% of the surveyed girls claimed they knew what engineering involved, 36% were undecided and only 5% agreed that they didn't know much about engineering. When asked if, in their opinion, engineering was mainly about building bridges, 74% disagreed, 13% were undecided and 13% agreed.

Beliefs about women in engineering

The results about the girls' personal beliefs and the beliefs of their family and friends are summarized in table 2 below:

<table>
<tr><th colspan="3">Personal Beliefs</th><th colspan="3">Beliefs of family and/or friends</th></tr>
<tr><td colspan="3">"Engineering is better suited for men"</td><td colspan="3">"Engineering is better suited for men"</td></tr>
<tr><td>Agree</td><td>Neutral</td><td>Disagree</td><td>Agree</td><td>Neutral</td><td>Disagree</td></tr>
<tr><td>5%</td><td>18%</td><td>77%</td><td>4%</td><td>22%</td><td>74%</td></tr>
<tr><td colspan="3">"Women engineers are generally unattractive"</td><td colspan="3">"Women engineers are generally unattractive"</td></tr>
<tr><td>Agree</td><td>Neutral</td><td>Disagree</td><td>Agree</td><td>Neutral</td><td>Disagree</td></tr>
<tr><td>4%</td><td>7%</td><td>89%</td><td>4%</td><td>7%</td><td>89%</td></tr>
<tr><td colspan="3">"Women engineers generally behave like men"</td><td colspan="3">"Women engineers generally behave like men"</td></tr>
<tr><td>Agree</td><td>Neutral</td><td>Disagree</td><td>Agree</td><td>Neutral</td><td>Disagree</td></tr>
<tr><td>5%</td><td>11%</td><td>84%</td><td>5%</td><td>11%</td><td>84%</td></tr>
<tr><td colspan="3">"It is hard for women engineers to get married"</td><td colspan="3">"It is hard for women engineers to get married"</td></tr>
<tr><td>Agree</td><td>Neutral</td><td>Disagree</td><td>Agree</td><td>Neutral</td><td>Disagree</td></tr>
<tr><td>3%</td><td>5%</td><td>92%</td><td>2%</td><td>11%</td><td>87%</td></tr>
</table>

Table 2: Beliefs

The results also showed a strong correlation between the girls' personal beliefs and the beliefs of their family and friends.

Pressure from family/friends

To the question, "I would like to pursue a career in engineering but my family and/or friends don't want me to", 91% disagreed, 8% were neutral and 1% agreed.

Exposure to women in engineering

The results to the question, "Do you know at least one woman engineer", are summarized in table 3 below:

No	Yes			
50%	50%			
	Through Family/friends	Through School	Through Media	Other
	70%	22%	13%	2%

Table 3: Exposure to women engineers

The last row adds up to more than 100% as some girls have been exposed to female engineers in different environments.

Discussion

The results show that, among of the 47% who knew which career(s) they wanted to pursue, 4% were interested in engineering. However, none of those who claimed being interested had indicated engineering as a possible career path. Among the 53% who were still undecided about they career path, only 8% could be considering a career in engineering. These results could not be attributed to the girls' lack of mathematical ability or interest, as they were Maths B and Maths C students. Also, these girls have not been exposed to male competition. As a result, it is assumed that their self-efficacy beliefs have not been undermined by boys' performance in science and mathematics. This is confirmed by the fact that a strong majority of the girls (77%) did not believe that engineering is better suited for men, and 92% of the girls did not perceive that women in engineering were any different from women in general. Neither could this result be attributed to social pressure, as only 1% of the girls surveyed indicated that they were interested in a career in engineering against the advice of their family and/or friends.

How, then, can this lack of interest be explained? Firstly, 41% of the surveyed girls do not know or are unsure about what engineering is. Also, although 59% claimed they knew what the engineering profession was about, they probably don't know the full spectrum of engineering. For example, 13% of the girls who thought they knew what engineering involved, also answered that engineering was mainly about building bridges. 51% of the girls who knew about their career path, were interested in a career in health (medicine, nursing, natural therapies, speech pathology, etc…). Many probably don't know that biomedical engineering is also devoted to improving the health and well being of the community, through the development and use of appropriate technological devices. More programs should be developed to inform high school girls about all the possibilities engineering offers. However, these programs should not target high school girls only. The results show a strong correlation between the girls' beliefs and the beliefs of their family and friends. These programs should therefore target the whole community.

The other result that could explain this lack of interest is that 50% of the surveyed girls have never seen a female engineer. Also, 70% of those who know at least one female engineer, have met them through family and/or friends, i.e. in a non-professional environment. It is therefore obvious that there is a need for female role models. This need has also been outlined in other studies (Hackett, Esposito & O'Halloran, 1989; Stringer & Duncan, 1985).

The difficulty is to be able to expose these girls to different role models, despite the small number of female engineers. School visits are one option, but there is a limit as to how many schools one female engineer is able to visit. Video programs picturing female engineers and distributed to different high schools are another option. Further research will focus on the different ways high school girls can be exposed to female role models, and the effect on their interest in the engineering profession.

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Acknowledgements

The author would like to acknowledge the Stuartholme year 11 and 12 girls, as well as their Mathematics teacher for kindly agreeing to help with this study.

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