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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