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DEVELOPING PROFESSIONAL ENGINEERING ATTRIBUTES THROUGH PROXIMAL AND DISTANCE EDUCATION.

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Introduction

Australian (and UK) university engineering education of the 1960s was highly focused on the analysis and solution of idealised problems isolated within discrete branches of engineering science. Even engineering design was often taught with idealised problems. The result was that most graduates entered professional employment without sound skills in dealing with real, holistic and complex situations. From the late 1960s employers increasingly voiced concern over deficiencies in various attributes of graduate employees of all disciplines. Recognition of the limitations in engineering graduate attributes led initially to the introduction of management studies and some emphasis on synthesis within engineering design. In Australia, as further limitations became known, piecemeal solutions resulted simply in increased course content.

Towards the end of the 20th century, factors such as digital technology, growth and economic impact of the creative industries, downsizing of large corporations and growth in the number of small enterprises radically changed the competency profile required for engineers to make significant and professionally sound contributions to this new economy. Through stakeholder forums, the Institution of Engineers, Australia (IEAust) determined the considered competencies required of modern professional engineers and the enabling attributes needed to be developed in graduates (Johnson, 1996) The IEAust made minor changes including the addition of 'business responsibilities including an understanding of entrepreneurship and the process of innovation' to the Johnson report recommendations and focused course accreditation on a demonstrated strategy and process to ensure these attribute outcomes, and a quality management system involving both industry and academic practising engineers.

This represented a need for fundamental changes to educational practice in engineering. Difficulties discussed below resulted in a revision of the accreditation requirements (IEAust, 1999) which recognised the need for a process of evolution. The changes to the Johnson Report recommendations made in the 1997 accreditation manual were also removed. Table 1 lists the 1999 IEAust attributes and the equivalent underlying generic attributes. Recent literature in Australia and the UK support these requirements, but indicate others including: critical thinking, intellectual curiosity and independent thought, making judgements, accessing and managing information, time management, language skills, broader engineering education as well as business skills, entrepreneurship and innovation as expressed in the 1997 accreditation manual. Further attributes could include: ability to sense when a design 'looks right', that design figures 'are in the right ball park', dynamic and 3D visioning ability, computer skills and political awareness (Lloyd et al., 2001, Chapter 9). This paper discusses teaching strategies to develop these attributes effectively in both on and off-campus students.

Teaching Strategies

Traditional assessment in engineering schools has focused on the summative evaluation of the power of students to recall, often in the context of mathematical skill and analysis directly relating to the specialist knowledge of each subject, using mathematical and essay style assignments, laboratory and (final year) project reports, and examinations. To effectively
develop the range of attributes discussed, effective formative assessment and teaching strategies which integrate the development of these attributes are essential to avoid erosion of foundation attributes of the profession such as skill in the mathematical analysis of engineering science problems. However difficulties in adopting more effective teaching strategies include; lack of teacher training in most Australian university engineering academics, increased teaching loads, and larger classes of greater cognitive diversity including range of maturity and background.

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Adopting new teaching strategies aimed at attribute development can lead to excessive work loads. Unless this issue is addressed, the strategies developed will be unworkable.

Table 1 IEAust Attributes (1999) and Equivalent Generic Attributes.

<table>
<thead>
<tr>
<th>IEAust Attributes (1999)</th>
<th>Underlying Generic Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ability to apply knowledge of basic science and engineering fundamentals</td>
<td>In-depth structured knowledge base (supporting attribute); ability to integrate, synthesise and apply theoretical and experiential knowledge from a range of sciences; problem solving.</td>
</tr>
<tr>
<td>2 Ability to communicate effectively, not only with engineers but also with the community at large.</td>
<td>Written, oral, and graphical skills. Range statement - from discipline specific to non-technical.</td>
</tr>
<tr>
<td>3 In depth competence in at least one engineering discipline</td>
<td>In depth structured knowledge base; procedural skills; ill-defined skills (e.g. ill structured problem solving and design).</td>
</tr>
<tr>
<td>4 Ability to undertake problem identification, formulation and solution</td>
<td>Problem solving.</td>
</tr>
<tr>
<td>5 Ability to undertake a systems approach to design and operational performance</td>
<td>Holistic focus; design skills; creativity.</td>
</tr>
<tr>
<td>6 Ability to function effectively as an individual and in multi-disciplinary and multicultural teams with the capacity to be a leader or manager as well as an effective team member.</td>
<td>Team skills; leadership skills.</td>
</tr>
</tbody>
</table>
7 Understanding of the social. Cultural, global, environmental, and business responsibilities of the Professional Engineer, and the need for sustainable development.

8 Understanding of the principles of sustainable design and development.

9 Understanding of and a commitment to professional and ethical responsibilities.

10 A capacity to undertake lifelong learning.

Deep Learning

Deep learning (or learning with understanding) is fundamental not only to the integrity of university education but, as the underlying generic attributes in Table 1 illustrate, is critical in developing most of the attributes discussed. It is also necessary for the development of 'clearly trained minds and high-level intellectual abilities' which according to the Business/Higher Education Round Table employers want of their university graduates (Prescott 1992), and also to place any field of study in an 'intellectual context', a concern of the Australian Vice-Chancellors' Committee (cited Bowden and Masters, 1993 p.60). However, heavy study loads (Pullin, 1999), coupled with the increasing need for students to take extensive part time work to support themselves (Cook and Cauchi, 2000), force minimisation techniques consistent with surface learning. Thus it is essential to first prune outdated and peripheral material.

Deep learning involves the integration of ideas and concepts and requires detailed information to be placed in context and perspective. Concept mapping - a procedure to diagrammatically represent the relationship between concepts - is one tool to portray the knowledge base. The structure of the assessment task is also significant in providing guidance.

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However deep learners, through reflection, try to relate the different aspects of their studies to personal experiences. To support and encourage deep learning the student should be provided with suitable experiences to reinforce this. Carefully planned laboratory experiments and hands-on experiences and activities can do this if provided at the appropriate time in the students learning cycle. Teachers can also support and encourage reflective practices by introducing their own experiential reflections. Research by Biggs and Telfer into teaching that gave evidence of deep learning showed that the most successful teaching strategies involved one or more of: appropriate motivational context; interaction with others, both teachers and peers; high degree of learner activity; and a well structured knowledge base (cited Gibbs, 1994, p. 173).

Wider range of teaching strategies.

The attribute approach requires adoption of a wider range of teaching strategies than the traditional. Problem-based learning and project based learning are excellent deep learning strategies that can support a wide range of the underlying generic attributes - particularly if group based. They can also introduce a new rich variety of assessment methods and are more tolerant of the increasing variations of background knowledge, learning styles and pace of the
student than traditional teaching and learning methods. Problem based learning has attracted growing attention over the last decade in a range of vocational disciplines - particularly medicine and dentistry. It is an ideal platform for delivering a range of attributes including development of attitudes, holistic problem solving and creative thinking. It is a significant departure from traditional teaching methods and to be effective needs induction and training of academic staff as well as considerable enthusiasm and commitment. Although papers have reported excellent results, cases have also been reported of less trained and enthusiastic academics delivering mediocre results.

Project-based learning is closer to the authentic professional situation than problem-based learning and more focused on educational outcomes than the final year project. Internationally there has been considerable interest in engineering courses that offer multiple group projects. Amongst the most notable is the University of Twente (Netherlands) project led program "Masters for the New Millennium" in which six projects drive the three year undergraduate part of the program.

The use of portfolios in undergraduate engineering higher education is relatively new. A project exploring this started in the mid 1990's in the UK. Directly focused on attribute development, it was practice based, requiring the systematic presentation of organised collections of evidence to demonstrate the development and achievement in four of the Engineering Council's attribute requirements (Ashworth et al., 1999). In addition to providing the students with a major focus on the development of the defined attributes, it is anticipated that it will engender the habit of reflective continuing professional development. A downside of this teaching strategy is that it is highly resource intensive and thus more suited to small groups.

Group poster presentations in which the presenters discuss and defend their work with peers and academics have gained increasing popularity as a higher education teaching strategy over the last twenty years. They have been more recently embraced in engineering higher education, particularly as part assessment of final year projects, and in problem-based and project-based learning. Research has shown that not only do they encourage deep learning and critical thinking, they support a wide range of attributes including logical and concise writing, graphical presentation, information literacy, creativity, and team skills. This strategy is also probably the best to develop peer learning - particularly if peer assessment is also involved.

**Attribute assurance**
A concern in using an integrated approach to attribute development is that extrinsically motivated students may strive to maximise assessment results by neglecting development of key professional attributes in which they may be seriously deficient in favour of other less essential skills. Eventually they graduate still deficient in key professional attributes. The following are approaches being developed by a few Australian engineering schools or their universities to address this concern.

**School based:**

- Use of (volunteer) professional engineers to assess the full range of attributes at an interview to be conducted near the end of the final year.

**University based (for all disciplines):**

- Encourage the development of evidence of the achievement of university nominated attributes through a computer based structured curriculum vitae. (Similar in principle to the portfolio project described above, but with considerably less staff input. Assessment is left to the employer.)

- Criteria referenced assessment (initially developed in the 1950s). Defined as the assessment of the extent to which a student achieves each of the goals of a subject (which can be framed in terms of attribute development) against previously specified criteria, it can be used to provide a more targeted formative learning driver to develop the essential attributes by separating assessment of essential attributes from the 'nice-to-have'. It requires minimum standards for each essential attribute before a pass can be awarded. Higher grades are awarded to those who achieve better standards for the essential attributes and/or the 'nice-to-have' attributes.

**Distance Education.**

The key advantages of distance education for the student are flexibility in time and place of study enabling students who have already embarked on a career to avoid career disruption, and also accommodate geographical relocation consistent with a changed family or work location. Although successful distance education requires the higher level of self-discipline and motivation usually more evident in mature age students, this is the main growth area in higher education. It provides not only for those who did not have the opportunity to go to university when they left secondary school but also the increasing numbers changing career direction, studying for higher degrees or engaged in continuing professional development to update or broaden their education (Ferguson, 1998).

Virtually all Australian universities now deliver off-campus courses, often concurrently with an equivalent on-campus program. Recognition of the educational benefits of distance education technologies has resulted in many being adopted in proximal teaching, while direct feedback from on-campus teaching supports off-campus program development. Other technologies effectively enable face-to-face teaching over a distance. Wong and Ferguson (1996) describe the example of the 'industrial campus' where video conferencing and proximal work-site lectures were provided for groups of industry based off-campus engineering undergraduate students.

Hybrid strategies such as distributed learning and flexible delivery further depolarise the two teaching modes. Flexible delivery adopts a range of learning strategies in a variety of learning
environments to cater for individual differences in learning styles, learning interests and needs, and variations in learning opportunities. Experience in the higher education sector in Australia and the USA has shown that the provision of highly individualised flexibility is problematic both in staff workloads and in poor student progress and completions. Distributed learning is a similar strategy but without the fully individualised flexibility envisioned by flexible delivery. Typically, a range of technologies are used to present information, activities to reinforce learning and support discussion between students, whilst proximal activities are used to develop skills best practised in a face-to-face environment. The burgeoning growth in Australia's off-shore education market is also strongly dependent on distance education and off-shore campus arrangements which most frequently use a hybrid strategy.

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**Developing engineering attributes through distance education.**

Recognising the special practical and experimental content of engineering courses, early concerns in the use of distance education delivery included:

• Inability to provide the physical demonstrations of concepts often provided in lectures.

• The reduced effectiveness of experimental work in reinforcing theory when there is an extended time difference between studying the theory and the performance of the experiment at an on-campus workshop.

• Lack of opportunity for discussions with lecturers, interaction with peers, and access to university services such as the library.

The focus on attribute development places even greater emphasis on these concerns. However solutions to many of these concerns have been developed over the last decade by the Deakin University School of Engineering and Technology through the use of various ‘educational technologies’.

• Videos and computer aided learning (CAL) programs were developed to deliver concepts that cannot adequately be conveyed by text and diagrams (Ferguson and Wong 1995);

• To overcome the excessive time delay in providing reinforcement of theory by experimental work, home experiment kits, CAL simulations of experiments and videos of real experiments (ibid) and more recently the direct control and monitoring of a fluids experiment and access to a flexible manufacturing cell were developed (Ferguson and Florance, 1999) These enable hands-on experiences and activities to reinforce deep learning to be available at the optimum time of study.

• Computer mediated communication, fax, and tele- and video-conferencing supported dialogue with lecturers and peers. These more immediate forms of communication enabled exploration and clarification of concepts and reinforcement by reflection. Index and abstract and full text databases and library borrowing facilities were made available through the Internet as are other university services.

The deep learning supported by these developments, in turn supports the development of higher level competencies such as critical thinking, analytical skills, creative thinking. Together with information acquisition skills (using the web based university library facilities), these skills support lifelong learning.
However group activities such as group projects, group problem-based and group project-based learning including peer presentations such as poster presentations, presented difficulties in distance education and, as discussed, they are significant strategies in attribute development. They are significant in effectively developing leadership and team skills and the support of innovation skills, peer learning, and communication skills. Nevertheless, students need to be able to communicate frequently and informally as a group at a working level to discuss calculations, designs, wording for reports, prepare presentations etc. At this level, the range of electronic communication strategies described still leave the distance education engineering student at a considerable disadvantage. They need a more convenient integrated and facilitative environment in which they can freely discuss their work, jointly contribute to design sketches, discuss calculations, brainstorm, work together on models, prototypes etc. When broadband Internet services become widely available and affordable, the use of desktop multi-window video-conferencing may have the potential to better support much of this, but ideally this would be linked to a concentrated on-campus workshop using a distributed learning approach.

Discussion and Conclusion

The stakeholder forums on the competencies and enabling attributes required for Australian engineers to practice successfully in the 21st century were necessarily generalised. However this was adequate to establish the new attribute approach and for universities to consider and develop strategies to achieve it. For a more focused outcome, the relative significance of these and a wider range of attributes to each engineering discipline may be more accurately established from extensive role analysis. The difficulties discussed earlier will make the fundamental switch to the attribute approach in proximal teaching a major challenge.

The delivery of engineering courses by distance education previously required development of a range of technology based strategies to overcome previous concerns specific to engineering education. However a more widespread adoption and sharing of the materials developed amongst engineering schools would better support the students as well as justify funding for further development. The attribute approach heightened the significance of these developments and introduced a new complication - group work.

The educational challenge is considerable, but, if successful, the teaching and learning outcomes in terms of professional development for our future engineers should be immense.

Bibliography


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