AC 2012-3134: ENGINEERING MANAGEMENT WITHIN AN UNDERGRADUATE BACHELOR'S OF ENGINEERING (HONOURS) PROGRAMME

Dr. Maxwell Reid, Auckland University of Technology

Maxwell Reid lectures in telecommunications engineering, computer network engineering, engineering management, ethics, and sustainability. He has researched and published on ethics and sustainability in engineering education, technology education, the role of a university as a critic and conscience of society, the need for an engineering code of ethics, and the principles of ethical and values-based decision-making in engineering. He has also published on effective teaching methodologies for engineering education in the post-modern period. Reid is the Deputy Head of electrical engineering in the faculty of design and creative technologies at the Auckland University of Technology, Saint Paul Street, Auckland 1010, Private Bag 92006, Auckland 1142, New Zealand. Contact at maxwell.reid@aut.ac.nz.

Engineering management within an undergraduate Bachelor of Engineering (honours) programme

Introduction

At the Auckland University of Technology (AUT) in New Zealand, we have addressed the crucial problem of how best to assure that the engineering students receive the best quality education possible to enable them to become useful citizens and professionals.

In terms of societal responsibilities, there has been a significant global change in engineering and societal attitudes, together with shifts in ideology and world opinion towards ethical and sustainable engineering. Engineers and engineering students are accustomed to scientific/factual knowledge and can find it difficult to make the shift to the social sciences, philosophical and management issues. An engineering lecturer needs to make this shift in philosophy. This curriculum serves only as the beginning of a life-long learning process and the concern at AUT was that not only should our undergraduate engineering students leave the university with an understanding of ethical, sustainable practice in the world of industry and commerce, but the respect which society and business accords the profession of engineering is enhanced by its members demonstrating this strong commitment to society and good engineering practice.

What has become equally relevant is the necessity to prepare engineers for management positions. This management capability is an emerging field for engineers and this conference contribution provides an explanation of the approach taken to the challenge. This paper describes the design of two engineering management papers within a Bachelor of Engineering (BE Hons) undergraduate engineering degree at AUT as part of an effort to meet the requirements of the new Washington Accord engineering graduate profile, and the consequent accreditation requirements of the Institute of Professional Engineers New Zealand (IPENZ).

The four-year BE programme is internationally benchmarked to the graduate profile agreed by the member countries of the Washington Accord (WA). In New Zealand, the Institute of Professional Engineers (IPENZ) acts as the approval and accrediting body in New Zealand and are a signatory of the Accord[1].

AUT Bachelor programmes

AUT offers a four year Bachelor of Engineering (BE) (honours) programme and a three year Bachelor of Engineering Technology (B Eng Tech) programme. The four year BE (Honours) programme at AUT is designed for students who wish to become engineers and prepares graduates for membership of IPENZ (MIPENZ). The mathematical underpinning of the degree develops the students' ability to formulate models. Graduates of this programme are able to analyse, predict and monitor engineering systems. The degree also utilises practical engineering examples and projects so that the students can place their knowledge in context, and includes the study of commercial, managerial and professional topics.

The BE graduate must have an in-depth engineering knowledge that allows a fundamentals-based first principles analytical approach to solve complex problems of a wide-ranging or conflicting technical problems and infrequently encountered issues that require abstract thinking, originality in analysis to formulate suitable models. Such problems may not be encompassed by standards and codes of practice for professional engineering, involving

diverse groups of stakeholders with widely varying needs. Such problems may have significant and wide-ranging contexts.

There is a distinct difference in the programmes' breadth and depth of investigation and experimentation. The BE graduate is expected to conduct investigations of *complex* problems including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions. However, the B Eng Tech graduate is expected to have the skills to conduct investigations of broadly-*defined* problems, with the ability to locate, search and select relevant data from codes, data bases and literature, design and conduct experiments to provide valid. The Education Act of 1989 requires teaching in bachelor degree programmes by staff mainly engaged in research, with an emphasis on the general principles and basic knowledge as the basis for self-directed work and learning[2]. Accreditation is confirmation that an institution or registered provider has shown it is capable of delivering an approved course. . Courses leading to degrees approved by NZQA may only be delivered by providers accredited to do so by the New Zealand Qualifications authority (NZQA). The AUT degree programmes conform to the NZQA definitions of a degree in so far as that our graduates of a Bachelors degree programme are able to:

1. Demonstrate knowledge and skills related to the ideas, principles, concepts, chief research methods and problem-solving techniques of a recognised major subject (or subjects, in the case of a double degree or a double major).
2. Demonstrate the skills needed to acquire, understand and assess information from a range of sources.
3. Demonstrate intellectual independence, critical thinking and analytic rigour.

At the International Engineering Alliance workshops in Canada in June 2009, Washington Accord signatories affirmed that in all future reviews of Washington Accord (WA) signatories for compliance with the Accord, the exemplar graduate profile developed and approved in 2009 would be applied and it was formally incorporated into the WA Rules and Procedures in June 2011.

The following changes are required:

- A stronger statement of the knowledge profile
- An expectation that graduates will be able to operate close to the frontiers of knowledge in their discipline
- An expectation that graduates have the capability to research rather than just investigate problems, and this is not to be at the expense of an integrating design-based capstone project
- An expectation that students are exposed to the practice (non-theoretical or codified) knowledge being applied within day-to-day practice in their discipline
- A stronger comprehension of contextual knowledge and the ability to apply that knowledge, e.g. in relation to design
- The ability to apply ethical principles.

The signatories agreed on the immediate implementation of the changes to the international graduate profile as the exemplar of the WA standard. Furthermore, it was suggested, that achieving this graduate profile requires four to five years of tertiary education, dependent on the entry level.

In a recent review the IPENZ Washington Accord Gap Analysis paper of 2010[1] it was established that there was a gap of at least 45-50 credits, and probably 60 in areas of engineering knowledge, projects and a range of contextual skills. However, changes to the Washington Accord necessitated the need for additional studies, and a full review of the Bachelor of Engineering (BE) took place at AUT in 2010 and consideration was given to enhancing the following aspects of the BE programmes

1. Design content.
2. Greater depth and coherency and in the analytical and engineering sciences subjects, with content updated.
3. An increase in research focus in the final year projects.
4. Enhanced contextual learning.

The IPENZ Washington Accord Gap Analysis paper[1] summarised the likely gap in the AUT qualification as a gap of at least 45-50 credits and probably 60 credits which will require:

1. 15 credits of engineering knowledge in which students demonstrate the capability to comprehend and apply engineering knowledge at the forefront of the discipline through research literature. This includes a demonstration of the ability to comprehend and apply a codified body of knowledge at the forefront of the practicing community.
2. 25-30 credits of capstone projects in which they undertake research, rather than investigative projects.
3. 5-15 credits in which a range of contextual skills include for example, working with other disciplines, ethical reasoning, impact of engineering on the community and a possible component based in industry[1].

To rationalise and introduce new papers, the offering of management papers was reviewed. AUT has for some time included engineering planning, ethics and sustainability in its programmes. However the decision was made in 2011 to review the management papers in the programmes. An ethics and sustainability paper was offered to the BE and B Eng Tech programmes. We had one management paper for the Diploma in engineering and offered to the Mechanical major of the B Eng Tech. We had a planning paper that was offered to the B Eng Tech and the BE programmes of all majors. None of these papers offered any guidance in the financial or organisational aspects of engineering. The B Eng Tech (electrical majors) received no management tuition at all.

It was decided to incorporate into the degree restructure a rationalisation of these management papers with a reduction of three management and engineering studies paper into two papers.

Rationale for the management papers
Many engineering students expect engineering science and competence in design to be more relevant to their chosen career than management skills. In modern engineering it is quite likely that an operational engineer may be required to be a manager with the skills to think broadly and act responsively. In fact, many professional engineers become involved in management early in their working life, and find their career development path leading to senior management positions.

In these senior roles, they find that their skills as communicators and conceptual planners can often be more demanding than their engineering skills. Quite often their decision-making includes dealing with uncertainty, where the time to investigate and document all the facts before a decision has to be made is a luxury that is not always applicable when dealing with uncertainty. Consequently, many engineers take postgraduate papers in financial and business management.

The feedback we receive from industry has in the past included criticism of engineering management with comments such as[3]:

- Lack of oral and written communication skills, particularly literacy.
- Narrowness of view.
- Lack of social and people management skills.
- Inadequate appreciation of economics.

Purpose of the management papers
Within the 2011 review the three so-called management papers were restructured into two, with a revision of content and the inclusion of the financial aspects of management.

The overall restructuring intention is present two new papers which introduce all engineering degree students to the operation of business organisations, and their interaction with their commercial environment and with society. Students are made aware of various aspects of management that are important to the practising engineer and how socially responsible management is an integral part of engineering. It is intended that these papers provide a base from which students may continue their management education.

The management paper structure
The first year BE students will share a common first year before they split into their majors during the second year. In this first year they take a common paper called Graphics and Communications Course. At this point they get there first introduction to engineering and society, a theme which includes ethics and sustainability, and will continue throughout other papers throughout the entire degree.

In the third year the students are required to take two management papers with the intention of introducing students to the operation of business organisations, and their interaction with their commercial environment and with society. Students are made aware of various aspects of management that are important to the practising engineer and how socially responsible management is an integral part of engineering. The papers also provide a base from which students may continue their management education.

Many engineering students expect engineering science and competence in design to be more relevant to their chosen career than management skills. However, professional engineers become involved in management early in their working life, and many engineers follow a career development path towards senior management.

The new and modified management papers *Engineering Management 1 and 2* assisting in closing the gap to the enhanced Washington Accord requirements in preparing the students to give appropriate and active consideration to social, cultural, ethical and environmental dimensions in design activities. This is done through presenting theoretical concepts and exercising them in assignments and case studies.

Diverse teams and a multi-disciplinary setting are being created through having all students in the School of Engineering attending the same paper at the same time and not being divided into the different engineering disciplines the school usually separates into. This applies to the overall delivery of the papers as well as the groupings for assignments and team exercises.

The AUT programmes also comply in their design as sequential study programmes in which content is progressively developed to the point where the graduates are not only prepared for the engineering industry for which the programme is specifically aimed at, but they are also prepared for postgraduate study and supervised research. The programmes prepare the graduates for advanced study as well as directed research and scholarship in the major specialisation areas of the degrees.

The Education Act of 1989[2] requires teaching in bachelor degree programmes by staff mainly engaged in research, with an emphasis on the general principles and basic knowledge as the basis for self-directed work and learning[4]. The AUT degree programmes conform to the New Zealand Qualifications Authority (NZQA) definitions of a degree in so far as that our graduates of a Bachelors degree programme are able to:

1. Demonstrate knowledge and skills related to the ideas, principles, concepts, chief research methods and problem-solving techniques of a recognised major subject (or subjects, in the case of a double degree or a double major).
2. Demonstrate the skills needed to acquire, understand and assess information from a range of sources.
3. Demonstrate intellectual independence, critical thinking and analytic rigour.

Graduate Capabilities Profile

Engineering undergraduates learn to apply their technical skills with higher-order intellectual problems where decision-making involves the application of engineering principles through the manufacturing or enabling process in the design of systems and the selection of suitable engineering components. However, engineers are also called upon to apply their skills in a wide variety of legal, institutional, management and environmental settings, which may include technology-driven social change. Their wisdom in engineering decision-making should be characterised by a sound knowledge and application of regulations and public safety. The graduate capabilities profile for this degree is divided into several areas in which the degree programme should contribute to the profile:

1 Knowledge of Engineering Sciences.

2 Analysis and Problem solving.

3 Design and Synthesis.

4 Investigation and research.

5 Risk Management.

6 Team Work.

7 Communication.

8 The Engineer and Society.

9 Management and Financial.

10 Practical Knowledge.

These areas of learning are noted in brackets in the following two papers.

Engineering Management 1

Learning Outcomes

On successful completion of this paper students will be able to:

1. Appreciate the history of management theory and models, industrial psychology, engineering as wealth creation and the history of technology. (8 & 9)
2. Appreciate the application of management to engineering organizations including a good understanding of its principles, concepts, terminology and functions. (2, 5, 7, 8 & 9)
3. Understand the importance of professional ethics & responsibilities for engineering managers, while recognising, defining and appreciating the organisational, legal, ethical and behavioural constraints on management decisions. (5, 8 & 9)
4. Appreciate issues concerning people in organizations and organisational culture. (9)
5. Demonstrate a good appreciation of the staffing function including; group behaviour, individual needs & career paths, motivational theories, conflict resolution, industrial relations, human resource management, the Employment Relations Act , performance measurement and control. (6, 8 & 9)
6. Understand the issues of leadership, theories of, styles of, sources of power, delegation, motivation, team building, productivity improvement, competitive advantages from manufacturing capability and case studies. (6, 7 & 9)
7. Understand the marketing process, benefits of, market segmentation, product life cycle, the marketing mix (the seven "P's"), market analysis (Ansoff, BCG, SWOT) and international trade. (8 & 9)
8. Describe the process of the management of risk and risk assessment, failure mode effects analysis, probability analysis, risk responses and contingency planning. (4 & 5)
9. Demonstrate an ability to analyse problems and follow clear decision-making processes, failure mode effects analysis, probability analysis, risk responses and contingency planning. (2 & 4)

Content

1. History of management theory & models, industrial psychology, engineering as wealth creation and the history of technology.
2. Management in engineering organizations; principles, concepts, terminology and

functions.

3. Professional ethics & responsibilities, the organisational, legal, ethical and behavioural constraints on management decisions.
4. People in organizations and organisational culture.
5. Staffing; group behaviour, individual needs & career paths, motivational theories, conflict resolution, industrial relations, human resource management, the Employment Relations Act, performance measurement and control.
6. Leadership, theories of, styles of, sources of power, delegation, motivation, team building, productivity improvement, competitive advantages from manufacturing capability.
7. Marketing, benefits of, market segmentation, product life cycle, the marketing mix (the seven "P's"), market analysis (Ansoff, BCG, SWOT) and international trade.
8. Management of risk and risk assessment, failure mode effects analysis, probability analysis, risk responses and contingency planning.
9. Problem analysis and decision-making, types of decisions, decision tables & trees and probability decision theory, analytical techniques; cost benefit analysis, linear programming, simulation, queuing theory and game theory.

Engineering Management 2

Learning Outcomes

On successful completion of this paper students will be able to:

1. Understand the relationship between engineering and society. (8)
2. Develop management strategies for changing conditions such as changes in workforce and markets. (9)
3. Understand and analyse business environments. (8.9)
4. Develop a business plan considering an organization's strategy. (2, 5, 9)
5. Describe a range of typical engineering projects, specify their scope and complete a feasibility study. (2, 4, 5, 6, 7)
6. Understand the context of new product development strategies. (6,7,8)
7. Demonstrate competence in operating under legal frameworks. (8)
8. Analyse and critically assess engineering proposals from an ethical and sustainable perspective. (2,5,6,7,8)

Content

1. Principles, definitions and applications of engineering management techniques.
2. Management strategies for changing conditions e.g. workforce, finance, technology, quality, markets, political.
3. Socio-technical systems, organizational infrastructures, business environments, globalization (outsourcing, international projects).
4. Analysis of financial accounts, sources of capital, budgets, discounted cash flow, investment appraisal, break even analysis.
5. Description of typical engineering projects, scope of feasibility studies.

6. Project risk identification and evaluation, risk analysis, strategies for reducing risks, case studies.
7. Project monitoring and control.
8. Innovation management, commercialization process, rapid product development, portfolio management
9. Engineering and society.
10. Legal concepts relevant to engineering
11. Moral and Ethical Theory.
12. Sustainability engineering.
13. Ethics in engineering practice.
14. Concepts relating to the application of sustainability engineering:
15. Eco Efficiency Cleaner Production; Sustainability Indicators; Industrial Ecology; Design for Environment; Life Cycle Analysis.

Conclusion

The overarching academic obligation with an undergraduate engineering degree is to facilitate informed thinking, to develop an intellectual independence and foster the ability to reason and think logically about issues that will confront students during their engineering career. Technical rationality is inevitably entwined and complicated by social values and the curriculum design is intended to facilitate the development of moral, ethical and sustainable integrity, together with an understanding of management issues. Students are made aware of various aspects of management that are important to the practising engineer and how socially responsible management is an integral part of engineering. The programme also provides a base from which students may continue their management education. In these two papers the students are encouraged to explore possible alternatives beyond the knowledge and constraints of the actual situation within their level of competence, as the beginning of a life-long learning process in their engineering careers.

The new BE curriculum is designed to interest and challenge undergraduate engineering students, and prepare them adequately for their intended profession. The concern during these paper developments was twofold: not only should our undergraduate engineering students leave the university with an understanding and ability to make good judgment in the world of industry and commerce, but these management papers need to be accepted and embraced by the students, rather than be viewed as soft subjects or a waste of time.

In documenting this work it is hoped to promote discussion that may assist other engineering educators to face the coming challenge with more confidence.

References

1. IPENZ (2010). Washington accord gap analysis. Institute of Professional Engineers New Zealand, Wellington: New Zealand.

2. Education Act (1989). Section 254. Retrieved 13th November, 2010, from http://gpacts. knowledge-basket.co.nz/gpacts/public/text/1989/an /080.html.

3. Wakelin, B. (1991). Operations Manager & Partner, Morrison Cooper Ltd. 1991 AEESEAP Engineering Education Conference, University of Canterbury, New Zealand.

4. NZQA (2010). Approval and Accreditation of Courses Leading to Degrees and Related Qualifications. Retrieved 8th December, 2011, from http://www.nzqa. govt.nz/assets/Providers-and-partners/Registration-and-accreditation/degrees-app-acc.pdf.