Educating Engineers for a Sustainable Future

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Abstract: Today’s engineers are required to plan, design, develop and maintain engineering projects and assets in a socially responsible and sustainable manner. While this need is being met to some degree in undergraduate programs, it is the professional engineer who has spent some time in industry after graduation who fully appreciates the requirement to balance the need for efficiency and economy in engineering practice with the wider needs of society and the increasing demand for sustainable development. To achieve this, it is necessary for the practising engineer to have an understanding of the principles of sustainable development, be innovative, have an understanding of asset management and maintenance, understand technological risks and work at the cutting edge of technology.

To address this need, the Faculty of Engineering and Surveying at the University of Southern Queensland has developed a Master of Technology Management program that combines postgraduate business courses with specialised courses in engineering and technology management. The first students enrolled in this program commenced in 2003 and delivery of the first courses commenced in the first semester of 2004. Students have been attracted to these courses from fields as diverse as business administration, project management and engineering technology as well as technology management. All are studying on a part time, distance education basis. Most courses developed for this program are new, and all balance social and environmental issues with the more traditional engineering requirements for economical and sound engineering asset design, development and management.

This paper describes this program, discusses the challenges faced in developing it and shows how undertaking such a program may benefit engineers and particularly those who have or aspire to managerial positions. In addition, it also describes how this type of education activity may develop future professional pathways for engineers. The authors of the paper have been extensively involved in developing the courses in the program.

The education and development offered by this program is aimed at developing engineers better equipped to be leaders of the society of tomorrow.

Keywords: Sustainability, management, technology, education
1. Introduction

The concept of a sustainable future is probably first ascribed to the “Our Common Future” report, or the Brundtland Report, first published in 1987 by the United Nations World Commission on Environment and Development. In this report, sustainable development is defined as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs". The report noted the importance of the concept of “needs”, and in particular the needs of the world’s poor; and the idea of limitations imposed by the state of technology and the social organisation on the environment’s ability to meet present and future needs.\(^1\)

Since then, there has been considerable discussion on sustainability, sustainable development and similar terms. For example, Johnson\(^2\) notes that these are contested terms. He observes that a 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. Thus the processes of striving towards sustainability, while still pursuing production goals and overall economic growth would be commonly referred to as sustainable development.

A common outcome of such discussion is that to achieve a sustainable future, any development project we undertake needs to carefully consider the needs of future generations, the ability of natural resources to continue to meet the needs of those generations, and what we can do to manage those natural resources to ensure that this occurs.

This argument can be extended to include all aspects of human endeavour. Thus, when we consider a sustainable future, we should be considering, in addition to environmental sustainability, concepts like social sustainability, economic sustainability, technological sustainability and sustainability in other fields of human endeavour and nature. Examples include a sustainable and cohesive society, the maintenance of historical artefacts, the ability to economically support the world’s population and management of technological knowledge.

Clearly the engineer has a significant role to play in this process as one important way of ensuring a sustainable future for the world and its population is through carefully planned development and implementation of advanced technologies. One of the ways in which this role can be developed is by inclusion of courses with a sustainability focus in engineering education curricula.

Part of this can be achieved by including in the engineering undergraduate curriculum courses that relate to sustainability concepts. However, as will be discussed in this paper, the large number of courses required to be studied by the undergraduate engineering student and the need to focus in undergraduate study on technical competence mean that there are limitations with developing sustainability concepts in the education of undergraduate engineers.

This paper discusses the issues in educating engineers for a sustainable future, explores the limitations of undergraduate courses in providing this education, and describes postgraduate initiatives being developed by the University of Southern Queensland to meet this need.
2. The key issues in educating engineers for a sustainable future

Engineers Australia has for some time recognised the importance of sustainability in engineering projects and has taken a leading role in ensuring that engineers plan, design, develop and maintain engineering projects and assets in a socially responsible and sustainable manner.

This is embodied in tenet 6 of the Code of Ethics of Engineers Australia, which states:

Members shall, where relevant, take reasonable steps to inform themselves, their clients and employers, of the social, environmental, economic and other possible consequences which may arise from their actions. 3

Engineers Australia also lists the following on its website, under the heading “What does Engineers Australia do for the community?”:

Contributes to community well-being through its diverse programs in sustainability, alternative energies, security. 4

Sustainability is a feature of the Engineers Australia report cards on infrastructure, and typically sustainability is embodied in a number of Engineers Australia awards. A strong and vigorous college of environmental engineering similarly supports the active role of Engineers Australia in promoting sustainability.

A related issue is globalisation, which can be thought of as the increasing internationalisation and integration of the world, such as in capital and financial markets, communication and transportation.

The importance of globalisation in the context of a sustainable future lies in its multi-national nature. Sustainability is now an international issue and needs to be tackled on a global basis. At the same time, some aspects of globalisation require careful treatment if they are to result in maximum long-term benefit and sustainability of communities both in developed countries and developing countries.

In the words of the joint declaration of Brazil, China, India, Mexico and South Africa participating in the 2005 Group of Eight (G8) Summit at Gleneagles, “all members of the international community should work together for the reform of the current international economic system to make it stronger and supportive of development” and “we urge the G-8 leaders and the international community to devise innovative mechanisms for the transfer of technology and to provide new and additional financial resources to developing countries under the UNFCCC and its Kyoto Protocol”. 5

Another aspect of globalisation is that engineers now operate in a global world, and it is quite possible for research for a particular project to be undertaken in one location, design in another and development in yet another. The engineers in all of these locations need to be aware of the ultimate purpose of the project and of the international ramifications of what they are undertaking from a sustainability focus.

The discussion can be summed up in the words of Johnston 2, who observes “sustainability needs to become a major driver for change in engineering education and practice” and “the
increasing complexity of engineering tasks has been one significant effect of globalisation on engineering practice.”

Because of this commitment to a sustainable future by the engineering profession, and the fact that sustainability is global, it is important for educators to foster and develop sustainable development concepts in engineering students.

The development of innovative thinking is an important aspect of the educational process. In an engineering programme this innovative thinking is focussed towards understanding current cutting edge technologies as well as developing new innovative technologies. Along with scientific developments, this engineering innovation thus becomes a very strong driver of technological progress. Now we must ask the question of how this innovation fits into a sustainable future.

It is easily argued that our modern way of life is underpinned by technological progress. It pervades all aspects of modern society: social, economic and environmental. Thus if sustainability is to be achieved, technological progress must be included in the development of a sustainable future, and some might argue further that is can supply the means to this end. Engineers have been and probably still are blamed for many actions of the past which have worked against this concept.

Being focussed on specific technologies engineers can easily develop tunnel vision and lose sight of the big picture especially sustainability. It is with this in mind that this concept is introduced in undergraduate programmes but more importantly must be developed into a real tool for practicing engineers via post graduates courses. Furthermore such courses must be directly applicable to practicing professional engineers and must been seen as a real asset to the corporations and institutions employing these engineers.

3. Undergraduate education for a sustainable future

Many engineering undergraduate courses now include courses (or subjects) that address sustainability and related issues. This may commence with a compulsory course addressing communication issues, which is the foundation for courses later in the curriculum that deal with concepts like the engineer and society, and engineering management.

For example, the University of Southern Queensland (USQ) offers the course *Principles of Professional Engineering and Surveying*, typically taken during the first year of the engineering curriculum, which teaches engineering investigation and report writing.

*Technology and Society*, which is typically taken in the second year of the engineer’s studies, builds on this foundation and deals with topics such as the history of technology, sustainability, environmental impact assessment, politics, economics, models of society, social impacts of engineering, a brief introduction to law and some key management issues such as management systems. This course clearly addresses tenet 6 of the Code of Ethics of Engineers Australia 1 (refer previous discussion in this paper), and in so doing lays the foundation of undergraduate education of engineers for a sustainable future.

Offer of this course in the second year of the engineering program means that all engineering graduates, from Associate Degree to Professional Engineer, are exposed to key concepts like
sustainability, globalisation, economics, and the need for the engineering graduate to relate to society and be innovative in addressing wider societal issues.

A third level course, *Engineering Management*, teaches management principles and practice for engineers and further develops the engineering student’s appreciation of the social environment within which they will practice, particularly those aspects of the law and ethics pertaining to the engineering profession. An optional fourth level course, *Engineering Management Science*, which provides the engineer a number of mathematical management tools, completes the undergraduate engineering management curriculum.

These courses provide the engineering undergraduate with a foundation in socially and environmentally responsible engineering principles and methods. One limitation of this education is, however, the relatively small proportion of such courses in the engineering curriculum, which after all is basically designed to teach technical competence. In the University of Southern Queensland engineering curriculum, such courses are at the most 12.5 per cent of undergraduate study. Their impact is therefore lessened by the other 87.5 per cent of courses that are required to be studied by the engineering undergraduate.

Further dilution of the education of undergraduate engineers in sustainable development occurs because the types of courses discussed above (with the exception of *Engineering Management Science*) are primarily verbally based rather than mathematically based, and therefore a number of students (particularly international students whose first language is not English) can find these courses difficult to understand, and therefore do not achieve as well in some of them as they would in technically based courses. As an example, the Technology and Society course over the past four offers has a drop-out rate of about 15 to 20 per cent, an overall pass rate of only about 65 per cent, and has only about 10 per cent of students achieving high grades (distinction or high distinction). These figures are worse for international students.

Undergraduate education therefore achieves a basic understanding of the principles of sustainability in graduate engineers, but falls short of providing the real focus on the type of global sustainable future provided by engineering innovation. Because of this limitation, the best opportunity of providing engineers with a deeper understanding of sustainability concepts is through dedicated postgraduate engineering education.

### 4. Postgraduate initiatives

The Faculty of Engineering and Surveying at the University of Southern Queensland offers several master level programs for engineers and technologists. These are:

- **Master of Engineering Technology (METC)** – a partial coursework and partial dissertation program aimed at developing increased technological skills in either engineering technologists or professional engineers
- **Master of Engineering Practice (MEPR)** – a portfolio based program aimed at providing opportunity for experienced technologists to gain recognition equivalent to a four year professional engineering program
- **Master of Technology Management (MTM)** – a coursework program linked with the Master of Business Administration aimed at combining technological and managerial skills for practising technologists and engineers
- Master of Professional Engineering (MPRE) – a partial coursework and partial professional portfolio (and/or research) based program that utilises Master of Technology Management and other courses to develop a higher level of engineering specialisation than the MTM.
- Master of Engineering (MEng) – a fully research based masters program.

A number of the coursework master degree programs also have associated postgraduate certificate and diploma programs. The university also offers a Doctor of Philosophy and an Engineering Doctorate.

This paper concentrates on the Master of Technology Management and its related programs.

5. The Master of Technology Management

The purpose of the Master of Technology Management is to produce graduates “that are equipped with essential management knowledge and an appreciation of the latest technologies much broader than the initial specialisation”, in order to equip them to manage complex technological or engineering businesses. 6

This program is completed by part-time external delivery mode, over a minimum of six semesters. It consists of twelve courses, four of which are core Master of Business Administration (MBA) courses and eight of which are specialised technology management courses. The first specialised technology management courses were undertaken by students in 2004.

The structure of this program is shown in Figure 1. In the recommended study pattern, students firstly study the four Master of Business Administration courses to gain an understanding of business management principles. They then study four basic specialised technology management courses, and finally select four courses from a suite of advanced technology management courses to complete their degree program.

An MBA with Technology Management specialisation, which has four selected core MTM courses plus eight MBA courses, along with a Master of Professional Engineering (which has a higher level of engineering specialisation than the MTM) and complementary Postgraduate Certificate and Diploma programs, are also offered.

This selection between alternative study paths enables learners to select an appropriate mix of business and technology management to suit their needs.

The Master of Technology program was developed out of the recognition that a large number of engineers and other qualified people 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. 6 This latter characteristic, which emphasises the crucial role of the technological manager in society, illustrates the importance of such a program to a sustainable future.

It is primarily aimed at attracting engineers and technologists who wish to develop management skills but want these to be in the field of technology management. They would come from both Australia and overseas, and would be likely to be ambitious and motivated, and see additional qualifications as a means of career enhancement.
The next section describes some of the elements of this program in more detail and show how it is linked to the concept of educating engineers for a sustainable future.

### 6. Master of Technology Management courses

At the moment, the following Master of Technology Management courses are available:

- Technological Impact and its Management
- Asset Management in an Engineering Environment
- Management of Technological Risk
- Technology Management Practice
- Technological Innovation and Development
- Future of Specialist Technology
- Engineering and Surveying Research Methodology

While a further course, *Towards Sustainable Development* is still being developed, students can gain credit for this course by studying selected business and science courses in sustainable development. This allows them to complete their MTM degree programs with existing courses.

Four selected courses are discussed briefly below to illustrate the role of the Master of Technology Management in educating engineers for a sustainable future.
6.1 Technological Impact and its Management

Technological Impact and its Management is founded on the premise that the world of today is one in which there is dynamic change in the creation and development of technology. Therefore, it is necessary for managers of technology to understand the impact of technological development and the ways in which it can affect the society in which we live and the controls necessary to achieve a positive impact on mankind.

This course reviews current technological development, evaluates its impact on the world on we live in, examines the relationship between modern society and technological development, and discusses the role of technological development on wealth creation and business. It also assesses the overall social need to manage such development as well as technology creation, transfer and exploitation.

This course therefore discusses technological development for the engineering manager from the aspect of the need for care, from a societal and environmental viewpoint, in the application of technological development.

6.2 Asset Management in an Engineering Environment

This course has been developed in recognition that in the modern world one of the highest expenditure for any government is the cost of developing and maintaining infrastructure.

It is designed to enhance the ability of technology managers in making better economical and financial decisions for the construction and maintenance of infrastructure assets. Such decisions, if properly made, will mean better use of resources in obtaining optimum performance and longevity of engineering assets. This course addresses this requirement by taking a strategic view of asset management, and then reviewing the overall asset management process and asset management economics. These principles are then applied in asset management operations, integrated asset management and asset management systems, and emerging issues in asset management.

6.3 Management of Technological Risk

The management of risk is important in modern technological management. For example, it is important to assess both the negative impacts and opportunities in the sustainable development and management of technological assets, both in a local and global context. There is a financial incentive to reduce this risk and to improve reliability, and increasingly, there are statutory requirements to address reliability and safety issues explicitly. In addition, there may be opportunities to manage risks to the benefit of the organisation. Consequently, people in technology management need to be aware of the tools and techniques used for the identification, assessment and treatment of technological risks.

In the first part of this course, risk management is discussed in the context of the Australian/New Zealand Standard for Risk Management AS4360:2004. In the second part of the course, learners apply risk management principles to technological and engineering projects and processes, and discuss the future of risk management, which is an important tool in evaluating the likely benefits and costs of alternative approaches in developing a sustainable future.
6.4 Technological Innovation and Development

Managers of technological innovation need to understand and manage key technological creation and development processes such as basic research, applied research and development, technology transfer and commercialisation. This knowledge allows a manager to, effectively, foster innovation, invention and development of new products and services from the moment of creation to the final commercial reality. In so doing the innovation manager benefits not only the firm but society as a whole.

This course aims to create effective innovation managers. It enables an understanding of research and development and the commercial creation of new products and services. It begins with understanding the concept of innovation and the management of research and development processes which have a propensity for quite variable results. Issues such as technical risk, intellectual property management, commercial risk and social impact are presented and evaluated. The whole underpinning of successful businesses through active innovation is discussed and evaluated. Technology transfer and strategic technology alliances are presented and viewed as part of the innovation process.

7. Development of the Master of Technology Management

7.1 Considerations in Development

The Master of Technology Management, along with its related programs, is designed to meet the needs of both potential learners and industry. The learners will already be practising professionals, located in both Australia and overseas, many of whom will be working in organisations that are dynamically changing and will have different levels of technological maturity. It is recognised that not all learners will be engineers, technologists, or scientists. Hence the courses in this program have been written to be understood by a range of professionals, the common thread being an interest in technological management for a sustainable future.

In developing the courses in this program, it therefore has been necessary to appreciate that learners will have differing needs, and will come from a range of organisations. These organisations, and the people in them, will have differing understandings of the concept of “technology management.” They will also have differing geographic and cultural backgrounds.

For example, the practice of asset management is likely to be quite different for a person in a developed country whose main concern is to ensure that an expected standard of service from a particular asset (such as a four lane asphalt surfaced road) is met, and a person in a less developed country, whose main concern might be justifying the construction of a road to a reasonable standard for its expected traffic and community needs. Course material should have examples of both types of situation.

Similarly, requirements and expectations may differ across geographical and political regions. Therefore, course development has needed to consider both Australian and overseas practice. For example, Management of Technological Risk is primarily based on the Australian/New Zealand Standard for Risk Management. However, the course developer has had to appreciate that there are also other equally valid risk management methodologies (for example, see Chapman and Ward) which need to be also considered.
Finally, learners will have different levels of access to the courses. In Australia urban centres, for example, most learners will have access to fast Internet access, and therefore they are likely to both expect and be provided with interactive on-line teaching materials. By contrast, people in remote areas of Australia may well have minimal Internet access, and those in remote parts of the world may have little or none. Assessment (such as assignments) from students in some more remote regions of the world may need to allow for good hand-written assignments as well as the normal typed assignment expected of a person who has ready access to computers. Course delivery needs to cater for all of these needs and expectations.

Therefore, when developing the courses in the program, it is important to be aware of the differing academic and professional backgrounds of learners, their needs and expectations and those of their employers, and the best way in which they can receive course materials and interact with lecturers.

7.2 The Course Development Process

Clearly, the diversity of interests and backgrounds has required the balancing of the challenge and interest for those learners with strong science, engineering, or technological backgrounds with the needs of people who do not have such backgrounds. Similarly, some students will want to understand the basics of the courses, while others will want to explore particular topics in depth.

Because of this range of student interests and backgrounds, the courses have been developed so that they provide sufficient material in the course material to give basic information, while maintaining a sustainability focus. This needs to be balanced by providing sufficient challenge for people who want to learn a topic in depth.

The need to meet the requirements of people with minimum technological background has required keeping mathematics in the courses in this program to a necessary minimum. However, this cannot be avoided in some cases.

As an example of this, some of the quantitative methods for risk analysis discussed in Management of Technological Risk require at least a basic level of mathematical skill, as well as at least a basic understanding of probability and statistics. In order to make the course relevant to people without a statistical background, sections of the course have been written to guide learners through the necessary basic processes. At the same time, the needs of advanced learners have to be considered. Therefore, the course has covered the necessary background material at outline level only, and then moved fairly quickly to applications. Those learners who need to know the theory in more detail have been directed to appropriate books and websites.

The development of courses to meet diverse learner needs is best illustrated by the example of developing Asset Management in an Engineering Environment.

Early tasks in designing and developing this course were to define those assets that should be managed by an engineer or technologist (the “technological assets”), assess what should be included in the course, and identify the likely profile of potential learners.

A further challenge was to decide on the way in which the course should be organised and presented to meet course objectives and to challenge learners. Thus, while the basic thrust of
the course is strategic, operational aspects of asset management are also addressed. Both need to have a whole of life, sustainable development focus.

A modular design has been employed, both for ease of study and to permit selected modules to be offered as future short courses suitable for possible industry training purposes. The first modules that students study deal with theoretical issues, while later modules in the course focus on application of these principles. Current and emerging issues like sustainability are addressed throughout the course. As with most courses in this program, a textbook is used to supplement study resources prepared by university staff.

The course uses guided research – 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 particular challenges in balancing the needs of learners and maintaining their interest. Material had to be carefully selected to meet these requirements.

To assist learners with mastering the amount of available material, the course has a number of activities that are classified into differing ranges of importance. The first level is essential tasks, which provide basic knowledge of the course material. Tasks classified as “important” are designed to provide further understanding. They include reading and understanding explanatory course or text material, or undertaking a reading or exercise that aids understanding of the principles being explained. Learners may also optionally further research course material (“background tasks”) or undertake in-depth research to understand it in more depth (“other tasks”).

Material in essential and important tasks is examinable and is accordingly structured to enable learners with minimal mathematical background to succeed in the course.

8. Implementation of the Master of Technology Management courses

As previously stated, the first three courses in the Master of Technology Management program were delivered in 2004. A further three courses were first delivered in 2005. All courses are expected to be available and delivered by 2007. Students enrolling for these courses are from diverse academic backgrounds, including business administration, project management, technology management and engineering technology.

All course material is provided in written paper form. While there can be some variation, this usually consists of an introductory book, a study book, and a book of readings. The introductory book contains information about the course, the study book contains the course material, and the book of readings a number of readings to aid understanding.

The written learning material has been enhanced with on-line discussion using the WebCT on-line teaching tool. This allows online discussion, notices, and posting of supplementary course material on the web for those with web access (the majority of students).

As communications continue to improve, the online learning facilities are expected to be enhanced. There have been many studies of this in the literature. For example, Macdonald 8, reported on the use of online interactivity in assignment development and feedback in
Britain’s Open University; Deeks discussed the use of web-based assignments for structural analysis; and Ferris, used web-based teaching for management engineering management.

9. The Challenges Ahead

Educating engineers for a sustainable future requires a combination of an understanding of sustainability, globalisation and innovation. The Master of Technology Management meets this requirement by combining business and engineering skills into an integrated package aimed at the innovative management of today’s and tomorrow’s technology based organisations, and is being developed in response to a changing world and changing demands. It is a distance education program aimed at attracting dynamic engineering and technology professionals worldwide.

Because of its need to be a dynamic program delivered by distance education to motivated professionals, this program has needed a tight focus, suitability for learners with a range of backgrounds and experience, and development within a tight timeframe. As the needs of the world and its society and environment change, the courses in this program will also need to adapt.

Part of the course adaptation process is meeting the needs of global communities, including developing countries. This requires better understanding and appreciation of their technological development and social, environmental and economic values and needs. Incorporation of this information into the course delivery process is expected to improve the relevance of course material to learners in local communities and at the same time improve understanding of global issues by all learners.

One of the key challenges ahead within the whole engineering profession will be the extent to which a traditional engineering undergraduate program, with its strong emphasis on technical training, will be able to produce the graduate who can effectively develop a sustainable future. The Master of Technology Management fulfils this need by offering postgraduate technology management education with a strong sustainability emphasis. Such a program will become the pattern for a well rounded engineering education in future.

USQ has traditionally targeted individuals as candidates for its course work master degrees. This has allowed many and varied industries to benefit in a general way for this upgrade of skills and knowledge. But recently specific industries have approached USQ for more specific technical training along with the aforementioned generic technology management skills for the engineering staff. Electricity generation and road infrastructure are examples in point. Thus there appears to be a need not only for individuals to attain skills toward a sustainable world but also for corporations to be empowered in the same way.

One possible format could be have a core generic skill for technology management plus elective areas tailored for specific industries either from USQ or their own in-house resources or even outsourcing to the appropriate experts be they in academia or industry.

10. Conclusion

While there are limitations in the management education of engineers at the undergraduate level because of their need to focus strongly on technical issues, postgraduate education provides the opportunity for them to broaden their skills in the management area. Through
combining business and technological education, the Master of Technology Management achieves this through a program tailored to the needs of engineers that in addition to teaching management principles also develops in learners the principles of sustainable development and social responsibility.

While there are a number of challenges to be overcome, this program and its related initiatives will therefore provide the opportunity for engineers to obtain a postgraduate education in engineering management that is equivalent to that of a specialised management qualification, and which also aids education of the engineer for a sustainable future.

References