THE IMPORTANCE OF SUSTAINABILITY IN ENGINEERING EDUCATION: A TOOLKIT OF INFORMATION AND TEACHING MATERIAL

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Abstract

As we face significant planetary issues such as global warming, ocean acidification, biodiversity loss and urban migration, it is clear that the engineering profession has a significant part to play in affecting the future of our planet. Australian engineer and incoming president to the World Federation of Engineering Organisations (WFEO) Barry Grear (AO), questions, '*What aspirational role will engineers play in that radically transformed world?* … *An ever-increasing global population that continues to shift to urban areas will require widespread adoption of sustainability. Demands for energy, drinking water, clean air, safe waste disposal, and transportation will drive environmental protection [alongside] infrastructure development.*'[1] Engineers have a critical role to play to help Australia and the world achieve sustainable development. It is clearly no longer possible to be a professional engineer and ignore the challenges and opportunities that arise from needing to achieve sustainable development. There is also a strong business case for engineering firms and university engineering schools to embrace sustainability. Whether you want to attract the best and brightest, or you wish to ensure that your students/employees are equipped with appropriate knowledge and skills to meet client needs, training for sustainability is now recognised as essential.

This paper discusses the urgent need for a transformation of engineering education globally – within higher education institutions and in professional development - to equip society with professionals who can address our 21st Century sustainable living challenges. It is critical that both the latest information about global systems and current and emerging endeavours to address sustainability challenges are integrated into engineering education in a timely manner. Such a transition involves content and cultural adjustment within the teaching fraternity, and there is no time to waste - the call for a transformation of graduate knowledge and capabilities is coming from both industry and our future learners. The paper discusses two current initiatives: 1) Development of a range of freely available, rigorously reviewed and robust online content resources for engineering education, called the '*Engineering Sustainable Solutions Program*'; and 2) Development of a rapid transition strategy for curriculum renewal in engineering education (through a 'curriculum renewal framework'), to meet the challenge of rapidly achieving sustainable development. Content development has been supported by international, national and state partners across government and industry, including UNESCO, Engineers Australia, The Federal Department of Environment and Water Resources, CSIRO, the National Framework for Energy Efficiency, and the Society for Sustainability and Environmental Engineering.

Background – Authors

The Natural Edge Project (TNEP) is a not-for profit partnership for research and education on sustainable development. Formerly hosted by Engineers Australia (2002-2006), the project is now hosted by the Centre for Environmental Systems Research at Griffith University, Australia (www.naturaledgeproject.net). TNEP's mission is to contribute to and succinctly communicate leading research, case studies, tools and strategies for achieving sustainable prosperity across government, business and civil society. We receive mentoring and support from a wide range of experts and leading organisations in Australia and internationally, through a generational exchange model. TNEP believes that our generation has an obligation - and an exciting opportunity - to be part of the solution in restoring the balance. We rely on mentoring and collaboration, using knowledge and experience from our collective network to ensure that efforts to make a positive difference make our children proud.

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[1] Grear, B (2006) The Future of Global Engineering – A Personal View. Available at: http://www.engineersaustralia.org.au/shadomx/apps/fms/fmsdownload.cfm?file_uuid=E8F3A8C7-FF5D-6B2F-AF25-FE7C80FB35E7&siteName=ieaust (accessed June 2007).

1. RESPONDING TO DANGEROUS CLIMATE CHANGE

Since the launch of the Al Gore Film *An Inconvenient Truth* (Gore 2006), the UK *Stern Review* (Stern 2006), and various reports from the Intergovernmental Panel on Climate Change (IPCC), there is now unprecedented global interest in how to achieve significant reductions to greenhouse gas emissions while meeting the escalating demand for energy, food, water, and goods and services. This interest in practical solutions is expected to rapidly increase as governments, companies and institutions in Australia and around the world commit to targets of reducing emissions in the order of 60 percent by 2050 (Smith and Hargroves 2007).

The 2007 launch of the IPCC's Fourth Assessment Report in April (IPCC 2007) effectively ended debate concerning key aspects of the science of climate change providing an 'unequivocal' link between climate change and current human activities, especially burning fossil fuels, deforestation and land clearing, the use of synthetic greenhouse gases, and decomposition of wastes from landfill. James Hansen from NASA, one of the world's leading scientists and members of the IPCC states, '*The question is, what is the level of global warming that would constitute dangerous climate change? We wrote an article in about the year 2000 in which we argued that 1 degree Celsius additional warming might be OK, but 2 or 3 degrees is not. But what's now become clear is that maybe 1 degree Celsius [additional to 2000] is dangerous, because already we're seeing on West Antarctica a net loss of ice and the ocean is warming and it is beginning to melt the ice shelves. The other change that has occurred, as many people predicted, is that China and India, the developing world, have increased their emissions at a significant rate in the last decade. So it really is becoming more urgent*.'

The report warned that if no action was taken, climate change would affect Australia in a number of significant ways including intensification of water security problems by 2030 in southern and eastern Australia from reduced precipitation and increased evaporation. Significant loss of biodiversity is projected to occur by 2020 in some ecologically-rich sites including the Great Barrier Reef and Queensland Wet Tropics, with Kakadu wetlands, south-west Australia, and alpine areas also at risk. Ongoing coastal development and population growth in areas such as Cairns and Southeast Queensland are also projected to exacerbate risks from sea-level rise and increases in the severity and frequency of storms and coastal flooding by 2050. Agriculture and forestry production is projected to decline over much of southern and eastern Australia by 2030, due to increased drought and fire. The IPCC report concludes (emphasis added), '[*Australia has*] *substantial adaptive capacity due to well-developed economies and scientific and technical capabilities, but there are considerable constraints to implementation and major challenges from changes in extreme events. <u>Natural systems have limited adaptive capacity</u>. Natural systems can be pushed by negative environmental pressures (pollution, climate change, overgrazing, algae blooms, overharvesting) past ecological thresholds at which point they collapse.*'

The IPCC reports and the Stern report strongly advocate a dual-track approach to dealing with climate change, comprising both *mitigation* and *adaptation* efforts; indeed much needs to be achieved through *mitigation* over a short span of time, to ensure that the resultant levels are something that the world can indeed *adapt* to. *'Inevitably society will need to adapt to a new climate regime as a result of a rapid increase in greenhouse emissions since the industrial revolution. There is a parallel and crucial requirement to focus on 1) reducing emissions of greenhouse gases and therefore stabilising the corresponding increases in global temperature; and 2) to prepare for an inevitable adaptation by society and the environment to an altered climate regime, assuming appropriate stabilisation is achieved'* (Hargroves 2007).

Dealing with mitigation and adaptation for climate change affects the full spectrum of professions. Consider for example the variety of skills and knowledge needed to: innovate technical solutions to greenhouse gas reductions and to redesign our built environments; to deliver sustainable food production and water supply; to implement disaster relief; to conserve biodiversity and develop plans for species preservation; to legally enforce pollution measures and to develop policy incentives for harnessing the power of the market; to manage borders and migration. Clearly, such an effort to equip society with essential knowledge and skills is an unprecedented task, in which education plays a critical role.

2. THE ROLE OF ENGINEERS IN SUSTAINABLE DEVELOPMENT

According to the World Federation for Engineering Organisations (WFEO), it is critical that engineering graduates are equipped with the relevant knowledge and skills to effectively address such challenges in society. Australian engineer, incoming WFEO president and former president of Engineers Australia Barry Grear (AO), questions, '*What aspirational role will engineers play in that radically transformed world?… An ever-increasing global population that continues to shift to urban areas will require widespread adoption of sustainability. Demands for energy, drinking water, clean air, safe waste disposal, and transportation will drive environmental protection [alongside] infrastructure development*' (Grear 2006).

It is very likely that future engineering will contain very little to do with creating fossil fuel-based products and services. While knowledge and skills in areas such as thermodynamics, fluid mechanics and structures will still be required, knowledge and skills in areas such as energy systems, chemical engineering, built environment, electricity production, engines and combustion processes etc. will change significantly. In addition, Sharon Beder from the University of Wollongong makes the point that Engineers often move into management, policy and government, financial institutions, and not simply traditional engineering careers (Beder 1997). Hence Engineers are making a contribution in all these areas to sustainable development using their technological knowledge to improve business and policy outcomes.

The Institution of Engineers Australia (EA), in the '*Australian Engineering Competency Standards – Stage 1 Competency Standards for Professional Engineers*' (EA 2004), states that (emphasis added), '*professional engineers are required to take responsibility for engineering projects and programs in the most far reaching sense… including understanding the requirements of clients and of society as a whole; working to optimise social, environmental and economic outcomes over the lifetime of the product or program*'. As the Peak Professional Body for engineering in Australia, EA sets the competency standards for engineers that must be aspired to by universities and other education institutions training and education engineers. In response to the need for engineers to deliver more sustainable solutions for society EA has incorporated specific competencies related to sustainable development into the Stage 1 Competency Standards for Professional Engineers as far back as 2004. Figure 1 is an extract of items specific to Sustainable Development from the current Australian Engineering Competency Standards.

PE2.2 Understanding of social, cultural, global, and environmental responsibilities and the need to employ principles of sustainable development

- Appreciation of the interactions between technical systems and the social, cultural, environmental, economic and political context in which they operate, and the relationships between these factors
- Appreciation of the imperatives of safety and of sustainability, and approaches to developing and maintaining safe and sustainable systems
- Ability to interact with people in other disciplines and professions to broaden knowledge, achieve multidisciplinary outcomes, and ensure that the engineering contribution is properly integrated into the total project
- Appreciation of the nature of risk, both of a technical kind and in relation to clients, users, the community and the environment

PE2.3 Ability to utilise a systems approach to complex problems and to design and operational performance

- Ability to engage with ill-defined situations and problems involving uncertainty, imprecise information, and wide-ranging and conflicting technical and non-technical factors
- Understanding of the need to plan and quantify performance over the life-cycle of a project or program, integrating technical performance with social, environmental and economic outcomes
- Ability to utilise a systems-engineering or equivalent disciplined, holistic approach to incorporate all considerations
- Ability to conceptualise and define possible alternative engineering approaches and evaluate their advantages and disadvantages in terms of functionality, cost, sustainability and all other factors

Figure 1: Extract from the Engineers Australia Competency Standard (EA 2004)

3. ENGINEERING EDUCATION FOR SUSTAINABLE DEVELOPMENT

In 500 BC, Chinese Tao patriarch Kuan Tzu is attributed with the following quote, '*If you are thinking a year ahead, sow a seed. If you are thinking 10 years ahead, plant a tree. If you are thinking 100 years ahead, educate the people.'* 20 years on from the publication of '*Our Common Future*' (Bruntland 1987) and 15 years since the first World Summit on Sustainable development (United Nations 1992), there has been a concerning lack of progress on embedding sustainability within higher education engineering education. In 1994, an international workshop of educators from the Asia Pacific region was convened in New Zealand to examine 'Fundamentals of Environmental Education in Engineering Education'. One of the conclusions of the workshop was that *all* engineers needed to be environmentally educated so they understood the issues involved in sustainable development and cleaner production. Beyond this, there was a need for perhaps a quarter of the profession to have a greater breadth of knowledge and additional skills in the handling of generality and complexity. What was needed, according to the workshop, was a holistic approach, a clear vision of system functioning, appropriate attitudes, skills and knowledge, systems skills, interaction skills, broad knowledge in specific areas, and exposure to significant issues (Elms and Wilkinson 1995).

This issue is also reflected within the Australian engineering education system. Most current Australian engineering degrees are still focused on 'old economy', 'fossil-fuel' engineering, involving linear 'heat, beat and treat' processes that don't tend to consider rethinking 'waste' at the end of the process. Even environmental engineering still tends to spend most of the program training students in end-of-pipe solutions rather than pollution prevention at the source. With diminishing resources at an institutional level, and time pressures to accommodate research and teaching requirements, many engineering departments are still doing no more than including flagship courses within existing programs. However over the last decade, the question of education for sustainable development has featured at most major education conferences. A 1997 international conference of the American Society of Engineering Educators identified technology in engineering education (the virtual university), sustainable development, and the impact of globalisation on engineering as the primary influences on future engineering education. The Conference recommended specific action to guideline curricula, provide teaching materials, and develop networks (Taskforce 1997).

The 2002 and 2004 International Conferences on Engineering Education in Sustainable Development (a predominantly European event) emphasised that Engineering education, especially higher education for the training of decision-makers, researchers and teachers, should be oriented towards sustainable development and should foster environmentally aware attitudes, skills and behaviour patterns, as well as a sense of ethical responsibility. The 2004 conference declaration reaffirmed that, "Engineering has responded to the needs of society and without a doubt, today's society requires a new kind of engineers." It also stated, '*Universities must redirect the teaching-learning process in order to become real change agents who are capable of making significant contributions by creating a new model for society. Responding to change is a fundamental part of a university's role in society. There is evidence that sustainable development has already been incorporated in engineering education in a number of institutions around the world. The United Nations Decade on Education for Sustainable Development (2005-2014) offers a great opportunity to consolidate and replicate this existing good practice across the international higher education community. Universities now have the opportunity to re-orient the traditional functions of teaching and research, by generating alternative ideas and new knowledge. They must also be committed to responding creatively and imaginatively to social problems and in this way educate towards sustainable development*' (2004).

Both the 2007 Australasian Association for Engineering Education conference in Melbourne (AaeE 2007) and the 2007 International Conference in Engineering Sustainability in Perth (SSEE 2007) feature engineering education for sustainable development as topics for deliberation. These topics include issues affecting the ability of engineering education to be changed, including for example organisational issues, resourcing issues, personality issues, funding issues, timeframe issues, and content issues. Papers discussing overstretched resources and declining student intake into environmental disciplines have featured in previous years and are likely to appear again. Some of the papers appearing in such conferences document success in including case studies and flagship courses (1st year, and masters level) but these efforts are rarely documented as part of a longer term strategic plan for curriculum renewal.

4. ELEMENTS OF CURRICULUM RENEWAL – ENGINEERING EDUCATION FOR SD

In order to make a transition to engineering education for sustainable development, it is critical to systematically address a number of common key elements (regardless of which academic institution) within the curriculum renewal process. Driving factors for undertaking a curriculum renewal process include the need to address industry and government demand for engineering graduates who are literate and competent in addressing sustainable development; the need to meet changing student expectations on course content (i.e. recruitment); and the need to respond in a critical timeframe of one decade. Table 1 summarises the identified key elements and the following sections expand on this summary.

Table 1: Curriculum Renewal Framework: Identified Key Elements

Awareness Raising Activities: Facilitate opportunities for staff and students to become aware of the current context of sustainability, through activities such as keynote lectures, keynote addresses, lunchtime seminars, media articles, and profiling of existing sustainability related initiatives and/or champions within the university.
Scoping Workshops with Key Staff: Undertake scoping workshops involving academic staff and other collaborators within the university hierarchy, to work through a SWOT Analysis (strengths, weaknesses, opportunities and threats) and Gap Analysis relating to sustainability, across the program/s of focus. This includes consideration of the university's 'Graduate Attribute' requirements for graduating students and how sustainability knowledge and skills relate to these requirements.
Desktop Audit & Classification of Programs: Identify all areas that omit or conflict with recognised sustainability principles, theory and application, through an assessment and classification of all courses in the program/s of focus (Category 1-5). Map out where courses need to be further developed with embedded sustainability content, renewed, or replaced. Include the scoping of resource and timing requirements for existing course renewal and new course development/ replacement. This element facilitates planned and strategic incorporation of content across (breadth) and within (depth) program curriculum, in order for students to successfully transition in their exposure to sustainability content within their discipline area. It is a collective Group, Departmental, Program and Course planning initiative that depends on participation of program and course convenors to scaffold the introduction of introductory, then detailed content on technologies and advancements appropriate to the discipline area. It is also critical that the audit and classification of programs acknowledges requirements for changes to course assessment and representation in course outlines.
New Curriculum - Existing Course Renewal (Integrated Approach) ***Introductory Level:*** Develop and embed sustainability content in a case study format, across first year courses in the program of focus. This needs a commitment from the first year teaching team with teaching support to embed materials into lecture/ tutorial/ workshop/ assignments/ laboratories/ site visits. ***Detailed (Intermediate – Advanced) Level:*** Develop and embed content for those courses identified as needing minor changes. For example, in a numerical methods course, this could involve bringing in programming that incorporates 'efficiency' calculations, which may not have been considered previously. Develop and embed content for those courses identified as needing major changes. Here it is important to address the issue of managing the lag time between training in sustainability content and the demand for graduates with this new knowledge and skill set. Planned and strategic integration of 'detailed' sustainability content will cater for such changing graduate skill requirements.
New Curriculum - New Course Development/ Replacement (Flagship Approach) ***Introductory Level:*** Develop a common introductory course for first year students to 'kick-start' the transition process. This may comprise either replacement of a previous course, or development of an existing course. This is also an opportunity to engage staff to begin their professional development in sustainable development content. This approach requires one or more 'champion lecturers' with teaching support. ***Detailed (Intermediate – Advanced) Level:*** Develop new courses to cater for learning in new sustainability content areas, previously not addressed in the program, replacing courses that no longer cater for graduate employment. As for existing course renewal, it is important to address the issue of managing the lag time between training in sustainability content and the demand for graduates with this new knowledge and skill set. Planned and strategic development and replacement with intermediate to advanced sustainability content will cater for such changing graduate skill requirements.
Outreach and Bridging (Recruitment): Use courses as outreach and bridging material for students considering study in the field. First year courses could be promoted to high schools as an accelerated Year 12 course. Masters first year/ introductory core courses could also be promoted internally to other sectors within the university, and to international potential student audiences.

4.1 Awareness Raising & Scoping Workshops

First and foremost, it is important that engineering educators are aware of the changing needs of graduating engineering students, so that they might begin to consider their role in developing the required knowledge and skills. This may be undertaken through activities such as keynote lectures, keynote addresses, lunchtime seminars, media articles, and profiling of existing sustainability related initiatives and/or champions within the university community.

It is also important to reassure educators during the awareness raising process, that making a transition to engineering education for sustainable development is very unlikely to mean ‘starting from scratch’. A common comment from engineering educators is that all programs already have a full quota of content and material critical to the students’ learning needs. The reality is that by the nature of curriculum design, courses will be ‘full’, however course content changes over time in response to changing student needs. For example, we are now teaching engineers skills and knowledge that did not exist as little as 5 to 10 years ago, particularly in the information technology and communications areas. Knowledge and skills about sustainable development covers information that is highly specific to the relevant engineering discipline, to concepts that overarch all disciplines.

Hence, rather than ‘throwing out’ the content of existing courses, the curriculum renewal process is about rethinking relevance of the theory, knowledge and application to meet societies needs in the future. This process may be facilitated through one or more scoping workshops, where key staff systematically develop a list of desired graduate attributes and a curriculum map for attaining those attributes. The workshops may contain the following aspects, based on collaborative workshop experiences between The Natural Edge Project, Griffith University, and the Queensland University of Technology:

1. Staff are provided with an overview of engineering and sustainable development, to ensure a common platform of understanding and language (detail dependant on staff level of awareness).
2. Working in smaller working groups, staff focus on a dimension of sustainable development (for example ‘Nature’, ‘Environment’, ‘Economy’ and ‘Well Being’) and brainstorm a list of graduate ‘indicators of success’ at a program level, with regard to graduates’ professional outlook (Character), content literacy (Knowledge), and competency (Ability).
3. Staff then prioritise this list and map sustainable development curriculum needs, with regard to what students should be exposed to in each year of their program of study.
4. Each staff member has the opportunity to review and develop all working group lists and maps, providing written notes to the original group. The original group then finalises the notes and presents their list and maps.
5. The resultant lists and maps from the workshops can then be compiled into a detailed curriculum structure for knowledge and skills related to sustainable development.

4.2 Sustainability Desktop Audit & Classification of Programs

The intent of the desktop audit process is to ensure that all courses within each degree program are congruent in language and message about sustainable development theory, knowledge and application, while catering for specific graduate attribute needs for the various engineering disciplines.

A ‘Sustainability Desktop Audit’ might proceed as follows:

1. The audit is initiated through a meeting with the audit team and the Head of School to clarify logistical requirements (i.e. documentation, including course outlines, summary of assessment requirements; and meeting room needs). The team may comprise (depending on curriculum needs), the Program Coordinator, an expert in sustainable development for the discipline area, and a teaching and learning staff member.
2. The audit team meets with the Head of School and those educators who teach into the program. The program’s courses are sequentially summarised in short presentations by the relevant Program/ Course

Convenors. During this time notes are made by the auditors using the audit checklist and clarification questions are asked where necessary. The presence of the rest of the course convenors and program convenors also provides an awareness raising opportunity for all staff members in relation to the program content and scaffolding.

3. Drawing from the key declarations and global commitments to sustainability by the relevant institutions and professional networks for the discipline area, each Course is then assessed against three main areas:

    1. **'Fundamental Principles/ Base Theory':** The first step is to consider the fundamental principles and base theory to investigate if the scope is sufficient to underpin the application to contemporary and emerging engineering applications and challenges.

    2. **'Knowledge':** The second step is to consider the information and knowledge provided by the course to demonstrate how the theory and principles behave and how the students can use this knowledge to engineer solutions and systems.

    3. **'Application':** The third step is to consider the examples used to demonstrate the application of the theory and knowledge to engineering challenges and whether the examples expose the students to contemporary and emerging applications of engineering.

4. The final 'score' for each Course is allocated using the Course Classification Guide according to the level of embedded sustainability content (see Table 2 below).

5. For each Course, a detailed SWOT analysis is undertaken, which includes recommendations for where content may be embedded. This information is documented in a 'Course Classification Summary – Detailed SWOT Analysis' (see example below).

6. The results and recommendations for each course are checked with the Course and Program convenors to check congruency of information and interpretations, and the report is finalised.

Table 2: Course Classification Guide

Classification	***Summary of Descriptors***
1	The course contains content and worked examples that address sustainability issues and innovations of relevance to the discipline area. Sustainability content is well integrated into the course (principles, theory and application), including representation in the course assessment. The Course Outline specifically addresses the sustainability content.
2	The course contains content and worked examples that address sustainability issues and innovations of relevance to the discipline area. Sustainability content (principles and theory) is well integrated into the course, including assessment, but there are few examples of application in the course content/ assessment. The Course Outline specifically addresses the sustainability content.
3	The course contains some content that address sustainability issues and innovations of relevance to the discipline area, although the principles and/or theory have not been completely updated. Sustainability content is not accompanied by up to date worked examples or case studies. Sustainability issues and/or innovations are addressed somewhat in Course Assessment. The Course Outline may include mention of the sustainability content.
4	The course contains a scattering of content (principles and theory) or worked examples (application) that address sustainability issues and innovations of relevance to the discipline area. The content is presented in an '*ad hoc*' manner and is isolated rather than integrated. The content and/or application addressing sustainability may not be reflected in Assessment. The Course Outline does not address the sustainability content.
5	There is no content (principles and theory) or worked examples/ case studies (application) addressing sustainability issues and innovations of relevance to the discipline area. The Course Outline does not address the sustainability content.

Course Name: **ENG101 Introduction to Thermodynamics**

Category Classification for Engineering Curriculum: **CATEGORY 2**

Course Code (Subject)	Fundamental Principles/ Base Theory	Knowledge	Application/ Practice
ENG101	√ *Clearly explained*	√ *Appears suitable*	~ *Room for improvement*

SWOT Analysis Summary:

1. Strengths:

- The Course appears to adopt a systematic approach to teaching momentum, mass and heat transfer. It currently incorporates an overview of some contemporary and recent applications of base theory to a range of emerging engineering innovations, providing a foundation for other courses in the program. Case studies highlight alternative energy sources (including biofuels, wind power etc.). Note that there is further opportunity to expand on these case studies by introducing industry best practice case studies.

2. Weaknesses:

- The Course lacks a 'meta-discourse' to contextualise learning within the program. This could be addressed in the outline for the course through the use of explanatory notes such as, '*A key component of addressing the goal of sustainable engineering solutions involves a solid understanding of momentum, mass and heat transfer. In order to contribute sustainable engineering solutions to society, students will need a strong grounding in the fundamental principles and base theory provided in this course*'.
- The base theory in the Course is in some cases still explained using unsustainable practices and processes. To address this, the Course could use introductory examples of cogeneration and heat exchange, providing the opportunity to both demonstrate application of the base theory and also to expose students to growing areas within sustainable engineering practice.

3. Opportunities:

- This Course has a clear opportunity to demonstrate to expose students to a range of sustainable technologies and alternatives to current unsustainable practices. For example, using the example of a traditional wastewater treatment plant to demonstrate systems thinking may leave students with the impression that services such as wastewater treatment can only be engineered in a chemical process, rather than the possibilities of biological solutions (eg living machines), or a combination of biological and chemical treatment.

4. Threats:

- Although students are exposed to base theory and knowledge, the Course examples appear to include limited applications of contemporary/ popular issues in engineering and environment. For example, to demonstrate atmospheric gas heat transfer, the Course might examine the range of greenhouse gases, and how they absorb and reflect heat in the atmosphere. (Refer to Attachment 2)

Additional Comments:

Additional notes and website references are provided below to assist the Course Convenor with addressing comments above:

– Sample Lecture: Green Chemistry and Engineering (available at: www.naturaledgeproject.net/essp); and
– Sample Lecture: Introduction to the Six Types of Greenhouse Gases (available at: www.naturaledgeproject.net/essp).

Figure 1. An example 'Course Classification Summary – Detailed SWOT Analysis' for a first year course in an engineering undergraduate program.

4.3 New Curriculum: Engineering Sustainable Solutions Program

This section provides an overview of content that has been developed to address the academic need for peer reviewed sustainable development content that is readily adaptable in the classroom. It addresses the elements of 'Existing Course Renewal' (Integrated Approach) and 'New Course Development/ Replacement' (Flagship Approach).

In recognition of the need for the Engineering profession to be equipped with the knowledge and skills to address climate change and contribute to sustainable development, the Engineering Sustainable Solution Program (ESSP) (Paten, Hargroves et al. 2005) has been designed to provide engineers and built environment professionals with a core understanding of sustainability issues and opportunities as they relate to their practice. It is designed to facilitate the effective incorporation of key pieces of information ('*critical literacies*') and the latest advances in sustainable design approaches ('*design principles*') relating to sustainability into engineering curricula and capacity building.

ESSP contains three portfolios of content: the Critical Literacies Portfolio (CLP) which covers information across the spectrum of sustainable development; the Technical Design Portfolio (TDP) which covers sustainable design in detail; and the Industry Practice Portfolio (IPP) which focuses on the latest advances on eco-efficiency opportunities for industry. Within this structure ESSP aims to provide teachers, lecturers, trainers and self learners with a suite of material that has been well researched, peer reviewed and trialled to assist in accelerating the use of such material. The program is freely available online, under a global *Creative Commons Attribution 3.0* licence. It is also supported through references and additional readings by the text book *The Natural Advantage of Nations: Business Opportunities, Innovation and Governance in the 21st Century* (Hargroves and Smith 2005), of which 9 of the 22 chapters are also freely available online. Development of the materials has been supported by grants from the following:

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– The Institution of Engineers Australia, College of Environmental Engineers (with particular support and mentoring from Martin Dwyer, Director Engineering Practice, and Peter Greenwood, Doug Jones, Andrew Downing, Tim Macoun, Julie Armstrong and Paul Varsanyi).

– The Federal Department of Environment and Water Resources ('Environmental Education Section').

– The Society for Sustainability and Environmental Engineering (with particular support and mentoring from Terrence Jeyaretnam).

Expert review and mentoring has also been received from Janine Benyus and Dayna Baumeister, The Biomimicry Guild (USA); Paul Anastas, Green Chemistry Institute (USA); Alan Pears RMIT University (AUS); Amory Lovins, Rocky Mountain Institute (USA); Tom Conner, KBR (AUS); and Mia Kelly, TNEP Working Group (AUS). We would like to add a special thank you to the Engineers Australia review panel Trevor Daniell, Thomas Brinsmead and David Hood.

Information about three courses is provided in the following subsections, as tangible examples of the content (full content is available at: http://www.naturaledgeproject.net/ESSP.aspx):

1) Critical Literacy Portfolio: 'Introduction to Sustainable Development for Engineering & Built Environment Professionals';

2) Critical Literacy Portfolio: 'Principles and Practices in Sustainable Development for the Engineering & Built Environment Professions'; and

3) Technical Design Portfolio: The Whole Systems Design Suite.

Courses (1) and (2) can be used to introduce the role of engineers and the built environment profession in achieving sustainable development. Course (3) can facilitate the rapid development or renewal of intermediate level courses covering sustainable design, using rigorous systems engineering design methodologies relevant for all engineering disciplines. The examples are detailed in the sub-sections below.

4.3.1 Introduction to SD for Engineering & Built Environment Professionals

The course 'Introduction to Sustainable Development for Engineering and Built Environment Professionals' is the introductory course in the Critical Literacies Portfolio of the Engineering Sustainable Solutions Program (ESSP-CLP) (Smith, Hargroves et al. 2007). It is summarised in the following 12 lectures:

1. ***Lecture 1: The Call for Sustainable Development:*** This lecture provides the context within which the call for sustainable development arose. The next 50 years has the potential for significant increases in the size of the global economy and significant reductions in poverty if society acts now to avert environmental damage and social deterioration.
2. ***Lecture 2: What has lead to a lack of Sustainability?*** This lecture develops an understanding of the core reasons for the current unsustainable situation. It also discusses increasing pressures on the planet's ecosystems and natural resources. It introduces the concept of externalities, where the real cost of increasing negative social and environmental pressures are not included in the price of goods and services.
3. ***Lecture 3: Sustainability as a Driver of Innovation:*** This lecture presents the next 'wave of innovation' theory. It discusses the emerging critical mass of enabling technologies that are improving business competitiveness and economic growth while reducing negative environmental pressures. It also discusses how the degree of success will depend significantly on the engineering and built environment professions.
4. ***Lecture 4: Emerging Technological Innovations:*** This lecture provides some examples of technological innovations that are beginning to drive 'the next Industrial Revolution' for sustainable development. It also notes the importance of existing innovations that may have the potential to be dramatically transformed.
5. ***Lecture 5: Efficiency - Resource Productivity Improvement:*** This lecture demonstrates that efficiency - doing more with less for longer - is a positive first step towards sustainable development. It introduces the concept of 'efficiency' and explains how it can lead to increased profitability and other benefits. It also discusses why efficiency on its own will not be enough to achieve sustainable development.
6. ***Lecture 6: Role of 'Systems' for Sustainable Development:*** This lecture introduces the main concepts of Whole System Design (WSD). It shows how WSD complements 'design for environment' and 'design for sustainability' strategies. It also introduces a ten step checklist for implementing WSD.
7. ***Lecture 7: The Concept of Biomimicry - An Historical Context:*** This lecture introduces the emerging field of Biomimicry and explains why it is such a powerful tool for innovation. It discusses Biomimicry as an innovation tool that can assist engineers and designers to look beyond 'efficiency' measures, to learn from nature's holistic approach to design.
8. ***Lecture 8: Green Chemistry and Engineering - Benign by Design:*** This lecture overviews how engineers, often working with chemists, apply Green Chemistry and Green Engineering principles to built environment issues. It discusses the key role of these professionals in assisting business, the economy and society achieve sustainable development.
9. ***Lecture 9: Rethinking the Application of Engineering Principles:*** This lecture discusses the need to rethink the way we apply engineering principles to solve problems. It discusses the need to reconsider what is taught in engineering education, including problem-solving and assumptions about future workplace roles.
10. ***Lecture 10: Creating Value from Sustainable Development:*** This lecture provides the argument to convince a company director or board that efficiency and sustainable development can be highly profitable as well as being the right thing to do. It overviews some of the most important studies proving that what is good for the environment can also be good for the bottom line.
11. ***Lecture 11: A Whole of Society Approach:*** This lecture discusses the collaborative roles of professionals in achieving sustainable development. It also presents ways in which governments can contribute to the transition to a more sustainable society.
12. ***Lecture 12: Effective Communication and Engagement:*** This lecture introduces the 'whole of society' approach and discusses the need to have a strategy to deal with the myriad of stakeholder groups that may be represented in a given project. Strategic Questioning is provided as an example of an effective communication mechanism that can facilitate 'contextually sensitive' outcomes. Multi-stakeholder engagement is also discussed.

4.3.2 Principles and Practices in Sustainable Development for the Engineering & Built Environment Professions

The course 'Principles and Practices in Sustainable Development for the Engineering & Built Environment Professions' is the second, intermediate course in the Critical Literacies Portfolio of ESSP (ESSP-CLP) (Smith, Hargroves et al. 2007). It is summarised in the following 12 lectures

1. ***Lecture 1: The Critical Role of Engineering:*** This lecture outlines (in more detail than the introductory course) historical changes and trends that have led to the call for sustainable development. It discusses the critical role of engineering and built environment professions in achieving sustainable development.
2. ***Lecture 2: Rethinking the Application of Engineering Design:*** This lecture reflects on the need to rethink the way engineering design is used to solve problems. It discusses how engineering institutions, scientific communities, the corporate sector and government are recognising the need to change the design scope; now seeking to design for sustainability/environment.
3. ***Lecture 3: Broadening the Problem Definition:*** This lecture discusses the scale and speed society needs to work at to reduce its negative impact on the global environment and improve resource productivity to prevent further overshoot of ecological thresholds. It also defines the types of performance targets engineers will need to help society achieve.
4. ***Lecture 4: Innovation to Achieve Factor 4-10:*** This lecture introduces the concept of 'factor efficiency improvements' in achieving large scale improvements towards sustainable development. It discusses the roles of government and research and development agencies in promoting such sustainable technology solutions.
5. ***Lecture 5: Efficiency – A Critical First Step towards Sustainability:*** This lecture continues to discuss 'efficiency' as a vital sustainability strategy, examining the roles of business, government and other organisations who are embracing efficiency to improve performance while reducing costs and pollution.
6. ***Lecture 6: Efficiency: Engineering Efficiencies (Energy, Water, Materials):*** This lecture explores how it is possible to achieve significant energy, water and material efficiencies with numerous everyday products and industrial processes. The lecture provides an overview of opportunities for engineers, including checklists for those seeking to achieve greater energy, water and materials efficiencies.
7. ***Lecture 7: Whole Systems: Achieving Whole of Systems Optimisation - Pipes and Pumps:*** This lecture introduces a 'Pipes and Pumps' case study from the Rocky Mountains Institute as an existing whole system engineering example of redesigning industrial pumping systems. The lecture also discusses how this example can be emulated for the whole system design of numerous other engineering systems.
8. ***Lecture 8: Whole Systems: 10 step Operational Checklist to Achieve Whole System Design Optimisation:*** This lecture discusses the operational steps involved in Whole Systems Design through the use of an operational check list.
9. ***Lecture 9: Design Inspired by Nature:*** This lecture discusses the concept of 'Biomimicry' and the principles on which the field is founded. It also discusses the role of the professional community in applying this methodology as a global network of Biomimicry practitioners.
10. ***Lecture 10: A Biomimetic Design Method and Information Sources:*** This lecture presents a methodology for applying Biomimicry principles to designing engineering solutions. It also provides details about sources and networks available to seek information about natural systems and Biomimicry design innovation examples.
11. ***Lecture 11: Definitions and Principles of Green Chemistry and Green Chemical Engineering:*** This lecture outlines the topic of 'Green Engineering'. It also explores the concept of 'Green Chemistry' and provides a description of the 12 Principles developed for this field of science.
12. ***Lecture 12: Green Chemistry and Green Engineering In Practice: A Succinct Overview:*** This lecture shows through example, explanation, and argument why the application of Green Chemistry and Green Engineering principles can make a significant contribution to sustainable development. It demonstrates that Green Chemistry and Green Engineering are no longer just ideas - they are the basis globally for a multi-billion dollar industry.

4.3.3 Technical Design Portfolio – Whole System Design Suite

Most current energy-using technologies are designed in three ways that are intended to produce an optimised design but actually produce ‘sub-optimal’ solutions, where components are optimised in isolation from other components, optimisation typically considers single rather than multiple benefits, and the optimal sequence of design steps is not usually considered. Whole System Design is a process whereby the inter-connections between sub-systems and systems are actively considered and solutions are sought that address multiple problems through one solution.

TNEP’s Whole System Design Suite (Smith, Hargroves et al. 2007) forms part of TNEP’s Technical Design Portfolio. It is targeted at intermediate to Masters level engineering courses, providing an introduction to sustainable design for all disciplines of engineering. The content incorporates insights from international sustainable designers including Amory Lovins, Bill McDonough, John Todd, Alan Pears and Janis Birkeland. These authors have found that through re-optimising the whole system design using the latest technological advances, it is possible to achieve ‘Factor 4’ to ‘Factor 100’ (ie 75% - 99%) efficiency improvements. This is because in the past, many engineered systems did not take into account the multiple benefits that can be achieved by considering the *whole system*. It has also occurred because of the specialisation of engineering over the last 100 years, which has limited incorporation of innovations from one engineering field into the design of another.

The Whole Systems Design Suite shows how traditional systems engineering design methodologies can be enhanced by the latest insights into whole system design for sustainability. The component lectures are as follows:

1. ***Lecture 1: Setting the Context:*** This lecture introduces the philosophy and practice of Whole System Design for Sustainability, building on solid systems engineering methodologies that are relevant for all engineering disciplines.
2. ***Lecture 2: Introduction to Systems Engineering and the Tradition of Systems Analysis:*** This lecture continues on from Lecture 1, providing the platform for implementation.
3. ***Lecture 3: Enhancing the Systems Engineering Process****.* This lecture demonstrates how Whole Systems Design builds on from traditional systems engineering design processes and hence why it is relevant for all engineering disciplines.
4. ***Lecture 4 & 5: Applying the 10 key operational steps for Whole System Design:*** These lectures provide an overview of numerous examples to show the benefits to engineers of taking a whole system design for sustainability approach.

The Whole Systems Design Suite then provides five technically rigorous case studies with calculations comparing the old way of designing engineered systems this new the new whole system design for sustainability approach. These include the following:

1. Case study – Industrial Pumping Systems.
2. Case study – Vehicle Design.
3. Case study – Computer Systems Design.
4. Case study – Building Temperature Control.
5. Case study - Domestic Water Systems.

4.4 Bridging & Outreach (Recruitment)

As the curriculum renewal process proceeds, it is important to address the recruitment of both undergraduate engineering students and masters students into the degree program. This can be achieved through the use of courses as outreach material, where:

- First year courses could be promoted to high schools as an accelerated Year 12 course; and
- Masters first year/ introductory core courses could be promoted internally to other sectors within the university, and to international potential student audiences.

5. CONCLUSION – FACILITATING CURRICULUM RENEWAL

It is critical that higher education institutions undertake curriculum renewal to make the transition to engineering education for sustainable development. In addressing the elements identified in this paper, it is recommended that professional bodies and universities consider a range of incentive mechanisms for encouraging teachers to commit to course renewal. These may include:

- Provision of funding for teachers to study in the new area (for universities this is termed teaching buy-out). This funding might be packaged with specific requirements, including becoming familiar with the topic area, identifying aspects that can be immediately incorporated into existing curriculum, and identifying aspects needing significant new course development.
- Provision of a budget, research assistance, and/or teaching buy-out, for teachers to renew their existing courses/ subjects and develop new courses where appropriate. This assistance might be packaged with a requirement to update content, assessment and outline.
- Strategic provision of resources to do a desktop review of current courses within engineering programs to identify areas of improvement, to ensure that the learning process embodies key teaching principles of teaching and learning.
- Encouragement through funding opportunities (eg small grants) for university staff to investigate research opportunities in this area (thus contributing to research kudos for the teacher and the possibility of increasing 'research led teaching' in the curriculum – another current university curriculum development driver).

In conclusion, the competency standards set out by Engineers Australia demonstrates that an understanding of sustainable engineering practice is expected of engineers emerging from high education institutions. What is needed now is for a curriculum transformation to engineering education for sustainable development. This is required in a timely manner that provides society with the best chance of changing the current course of social and environmental degradation, and in particular to mitigate and adapt to climate change. Indeed, engineering education focused on sustainable solutions may serve to also increase the popularity of engineering as a career, where it is possible to make a significant positive difference to the future of society and the health of the planet.

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