ENGINEERING EDUCATION FOR SUSTAINABLE DEVELOPMENT: A REVIEW OF INTERNATIONAL PROGRESS

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Abstract:

Since the late 1980s there have been increasing calls around the world for embedding sustainability content throughout engineering curricula, particularly over the past decade. However in general there has been little by way of strategic or systematic integration within programs offered by higher education institutions (HEIs). Responding to a growing awareness towards the issues surrounding sustainability, a number of professional engineering institutions (PEIs) internationally have placed increasing emphasis on policies and initiatives relating to the role of engineering in addressing 21st Century challenges. This has resulted in some consideration towards integrating sustainable development into engineering curricula as envisaged by accreditation guidelines. This paper provides a global overview of such accreditation developments, highlighting emerging sustainability competencies (or 'graduate attributes') and places these in the context of relevant PEI declarations, initiatives, policies, codes of ethics and guideline publications.

Keywords; engineering education for sustainable development, sustainability, accreditation, curriculum renewal, competencies, graduate attributes.

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1. ENGINEERING EDUCATION FOR SUSTAINABLE DEVELOPMENT

1.1. Introduction –conceptions of terms

While the terms ‘sustainable development’ (SD) and ‘sustainability’ are often used synonymously as encompassing a cause and effect relationship, neither of these terms themselves have universally agreed meaning. In 1987, the Brundtland Commission’s report (WCED, 1987) defined sustainable development as *‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’*. This definition has attained universal traction and is seen by many who recognize the current unsustainable nature of society as a means of achieving sustainability. For example, the Royal Academy of Engineering published guiding principles on engineering for sustainable development in 2005, to address the problem that, *‘We are exceeding the capacity of the planet to provide many of the resources we use and to accommodate our emissions, while many of the planet’s inhabitants cannot meet even their most basic needs’* (RAE, 2005).

Others argue that sustainable development, even by the Brundtland definition, can be (and often is) interpreted more liberally, in such a way that entrenches a ‘business as usual’ paradigm, and thus can actually prevent the realization of a sustainable future. For example MIT chemical engineering professor emeritus John Ehrenfeld (2008, pp.5;21) suggests that; *‘sustainable development is not actually a vision of the future. It is merely a modification of the current process of economic development … All* [its ‘programmatic prescriptions like eco-efficiency’] *have some potential to mitigate or slow down the unsustainable trajectory of the globe, but all are only quick fixes.’* Ehrenfeld (2008, p.7) thus encapsulates the problem with SD as he sees it: *‘Almost everything being done in the name of sustainable development addresses and attempts to reduce unsustainability. But reducing unsustainability, although critical, does not and will not create sustainability.’*

Ehrenfeld defines sustainability, as *‘the possibility that human and other life will flourish on the planet forever’* (Ehrenfeld, 2008, p.6). This concept is analogous to the concept of backcasting (the antithesis of forecasting), whereby some future (sustainable) state is envisioned, and then one works backwards to develop a current platform which has the fundamental potential to accommodate the future envisioned state. This will inevitably involve nudging at cultural norms – that is, helping alter observed behavioural patterns over time and space, through clever and innovative design. Backcasting thus represents an envisioned future, which Stasinopoulos *et al* describe as representing *‘the desired outcome rather than the transition … so as to be applicable at many levels, to many fields and industries. A general vision will encourage a flexible system that can adopt to unforeseen technological and political disturbances.’* (Stasinopoulos *et al*., 2008, p. 88).

With such perceptions in mind, the Brundtland definition has underpinned most discourse since its publication, spawning widely recognized terms such as ‘education for sustainable development’ (ESD) and ‘engineering education for sustainable development’ (EESD). Indeed, the United Nations (UN) has been instrumental in developing these concepts and it has named the decade 2005-2014 the ‘UN Decade of Education for Sustainable Development’ (DESD), led by UNESCO (UNESCO, 2005). The UN defines ESD as education that encourages *‘changes in behaviour that will create a more sustainable future in terms of environmental integrity, economic viability, and a just society for present and future generations’* (UN, 2002); increasing the capacity of individuals, groups or organisations to contribute to sustainable development, through content and skills acquisition.

Within this context, the term 'sustainable engineering' has a variety of meanings. For example, Dowling's definition of sustainable engineering includes a clear eco-efficiency focus: '*practices that promote environmental, social and economic sustainability through greater resource efficiency, reduced pollution and consideration of the wider social impacts of new technologies, processes and practices*' (Dowling et al, 2010, p. 333). A potential issue with approaches that are characterized by improving efficiencies, is the phenomenon known as the 'rebound effect', whereby gains in efficiency can be negated by subsequent increases in consumption levels without the necessary corresponding change in mindset (Clift, 2006). Technological improvements in the absence of conceptual change might thus be characterized as putting the cart before the horse, with similar consequences. Sustainable engineering literature often includes commentary regarding the importance of technological eco-efficiency particularly in the short term, accompanied by longer term cultural and behavioral change.

Despite the rapid growth in discussion about the need for engineering education to incorporate sustainability knowledge and skills, an internet search of definitions did not provide any documented definitions for the widely used term 'engineering education for sustainable development' (EESD); nor any definitive lists of desired competencies, graduate attributes or learning outcomes. However, according to the World Federation of Engineering Organisations (WFEO, 2002) (WFEO represents 15 million engineers from more than 90 nations), EESD means education that encourages engineers to play, *'an important role in planning and building projects that preserve natural resources, are cost-efficient and support human and natural environments'*. On the basis of this statement, EESD can be considered to be an all-encompassing term, including the teaching of technical, social and economic aspects of development. For the purposes of clarity, the term EESD will henceforth be used through the remainder of this paper in such a broader, all-encompassing sense, whereby it envisages the achievement of sustainability as a function of both paradigmatic and technological change.

1.2. Calls for a new conceptualization of engineering

Professional organisations around the world have been declaring an urgent need to keep up with the pace of change and forming collaborations to make progress, in particular since the early 1990s. For example, in 1992, together with the International Union of Technical Associations and Organizations (UATI) and the International Federation of Consultant Engineers (FIDIC), WFEO created the World Engineering Partnership for Sustainable Development (WEPSD) (Carroll, 1992), which has since been active in promoting a new vision of engineering as one which befits 21st Century challenges (Ridley and Ir. Lee Yee-Chong, 2002). Many have hypothesized that 21st Century engineering will have little to do with creating fossil fuel-based products and services (Cortese, 2007; RAE, 2007; Borri, 2008). Australian engineer and 2009 WFEO president and former president of Engineers Australia Barry Grear questions the type of world that engineers will presently inhabit (Grear, 2008);

> *'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'.*

However, it has been pointed out that these challenges will require a new approach to engineering practice, one characterised by a broader more expansive self conceptualisation. In addressing this situation, in 2009 the UK Engineering Council concluded in their report *Guidance on Sustainability for the Engineering Profession*;

> *'A purely environmental approach is insufficient, and increasingly engineers are required to take a wider perspective including goals such as poverty alleviation, social justice and local and global connections. The leadership and influencing role of engineers in achieving sustainability should not be under-estimated. Increasingly this will be as part of multi-disciplinary teams that include non-engineers, and through work that crosses national boundaries.'* (ECUK, 2009)

2. SIGNS OF PROGRESS INTERNATIONALLY

There has however been substantial progress made internationally over the past decade or so in relation to EESD. A review of such progress as presented in the literature by individual authors or groups is outlined in Appendix 1. Additionally, there have been a number of key international surveys on the state of EESD. These are summarized in Appendix 2, and the latest two, which relate to the state of EESD in the USA and Europe will be reviewed.

As part of the US Center for Sustainable Engineering study, Allen and others at the University of Texas at Austin, Carnegie Mellon University and Arizona State University (Allen et al, 2008) have produced a comprehensive review of accredited engineering programs that incorporate sustainability concepts across the USA. While just 20% of programs responded, 80% of these report *'teaching either sustainable engineering focused courses or integrating sustainable engineering material into existing courses'*. The main findings of the study were that courses concentrate primarily on smaller systems, particularly those limited to the firm (gate-to-gate or design for environment) or product (cradle to grave or environmental life cycle analysis), while less than half of the courses address larger systems that examine relationships between different firms or industrial sectors (industrial ecology) or between industrial and non-industrial sectors (cultural and social dimensions). The authors also found that sustainability engineering material was taught to classes of predominantly upper division undergraduate and graduate students, and while discrete sustainable engineering courses seemed to be the most common approach, material is also incorporated throughout programs. The study reports the following among its key findings:

> *'The engineering education community is now at a critical juncture. To date, there has been a significant level of "grass-roots" activities but little structure or organization. The next step will be for engineering accreditation bodies to think critically about what should or should not be included in a curriculum into which sustainable engineering has been incorporated. The path forward will require the evolution of a set of community standards.'*

The authors also report:

> *'We believe a long-term goal of 21st century engineering education is to enable practicing engineers to incorporate tenets of sustainability into all phases of their*

> *practice, so that "sustainable engineering" eventually equates with "good engineering".'*

One aspect of the study which makes comparison of practice difficult was its subjective nature; *'the questionnaire [provided] did not provide a comprehensive definition of either "sustainability" or "sustainable engineering," which reflects the state of the art, but necessarily increases the subjectivity inherent in these results.'*

This is also the case in a biennial European based study by the EESD Observatory, which aims to report on *'the extent that sustainability is embedded in European engineering education'* (EESD Observatory, 2006; 2009). It has published rankings based on both self selection with the aim of measuring progress against the Declaration of Barcelona (EESD, 2004). Embedding SD within the curriculum was just one of five criteria used to rank institutions. The results here were not very enlightening as all institutions were either given a (self selecting) score for embedding of either 100% or 0%; neither of which is very credible outcome for what is in reality an elusive entity to measure! Two other criteria are *'the number of courses and specializations on SD offered at undergraduate level'* and *'postgraduate program on SD divided into number of Master Programs offered by the university, number of credits (ECTS) and when the program started'* relate to programs. The report does not offer much by way of analysis apart from commenting that more universities took part compared with a similar exercise two years previously (EESD Observatory, 2006) and that more received higher grades.

In conclusion, the literature suggests an *ad hoc* and highly variable approach to such curriculum renewal and it is concluded that there has not been a large-scale transition to producing engineering graduates with the knowledge and skills to meet the changing needs of the profession over the coming one to two decades in particular. Moreover, while engineering education has undergone periods of curriculum renewal to embed professionalism, ethics, and health and safety, the profession has not had to make a significant shift in the way it fundamentally teaches students across all disciplines since the first engineering professionals emerged following the Industrial Revolution (Jorgensen, 2007).

3. DECLARATIONS, ACTION PLANS, POLICIES AND OTHER INITIATIVES

3.1. Key declarations and action plans

Over the last two decades there have been growing global calls for change in higher education towards ESD from a variety of international bodies. A number of resulting declarations and action plans which have been explicit about the need for transitioning to ESD as soon as possible are highlighted in Appendix 3.

These have formed the broader context for calls for EESD more widely. The 1997 report of the Joint Conference on Engineering Education and Training for Sustainable Development in Paris called for sustainability to be *"integrated into engineering education, at all levels from foundation courses to ongoing projects and research"* and for engineering organisations to "*adopt accreditation policies that require the integration of sustainability in engineering teaching"* (JCEETSD, 1997). This was followed by the 2004 Declaration of Barcelona (EESD, 2004) which outlined how universities and engineering educators need to change;

> *'to prepare future professionals who should be able to use their expertise not only in a scientific or technological context, but equally for broader social, political and*

> *environmental needs. This is not simply a matter of adding another layer to the technical aspects of education, but rather addressing the whole educational process in a more holistic way, by considering how the student will interact with others in his or her professional life, directly or indirectly. Engineering has responded to the needs of society and without a doubt, today's society requires a new kind of engineers.'*

The Declaration of Barcelona (EESD, 2004) also made a radical call on institutions and universities to redefine their missions *'so that they are adapted to new requirements in which sustainability is a leading concern'* and for universities to '*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.'* Additionally, the World Engineers' Convention in 2004 (UNESCO, 2004) also published a declaration on engineering and a sustainable future.

From a qualitative review of mainstream international and regional engineering conference programs spanning the last 5 years (including the Australasian Association of Engineering Education annual conferences, the Global Colloquia on Engineering Education, and the International Conference on Engineering Education) it is clear that major engineering forums are now featuring engineering education for sustainable development as a theme for submission and presentation. Topics covered in submitted papers 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 are common features within the programs. Some of the papers appearing in such conferences document success, including case studies and flagship courses (first year, and masters level) but these efforts are rarely documented as part of a longer term strategic plan for curriculum renewal.

Recently there has also been a shift in some global 'mainstream' engineering education conferences, with regard to the themes and requests for papers. For example, the 2008 *7th Global Colloquium on Engineering Education* (GCEE) theme was 'Excellence and Growth in Engineering Education in Resource Constrained Environments', with a research track focused on 'Inferring and Designing Engineering Education Practice from Research and Societal Context: To what extent should engineering educators collaborate globally to re-engineer their programs?' (ASEE, 2008). However, although the 2008 International Conference on Engineering Education theme was 'New Challenges in Engineering Education and Research in the 21st Century' including invited topics on environmental challenges and the role of Engineering Education in Sustainable Development, only two out of more than 235 presentations, and three out of more than 65 posters explicitly addressed either of these topics, and these were case studies (ICEER, 2008).

3.2. Policy statements

Alongside calls for greater emphasis on EESD internationally, PEIs have also been envisaging a increased role for sustainability and sustainable development among the engineering community, as evidenced in policy statements and other initiatives as shown in Table 4.

Table 1. Examples of strengthening professional requirements for EESD

Date	**Key Documents Outlining Professional Requirement**
1990	FIDIC introduced environmental policies including guidelines on the obligations of the consulting engineer with respect to their projects and clients 'Engineers should provide leadership in achieving sustainable development'. (FDIC, 2004) FIDIC, the United Nations Environment Program (UNEP), and the International Chamber of Commerce (ICC) developed training programs for their members and for industry to provide guidance on how to describe and analyse environmental issues as well as setting up environmental management systems. (UNEP, undated)
1994	Engineers Australia developed a policy on sustainability in 1994 which required that 'members, in their practice of engineering, shall act in a manner that accelerates achievement of sustainability' (Carew and Mitchell, 2006).
1992 – 1996	World Engineering Partnership for Sustainable Development - WFEO, FIDIC and the UATI - formed a collaboration to lay the groundwork for the many programs in support of sustainable development that are being pursued by WFEO, FIDIC and other international organisations through their members and committees.
1997	Eighteen national and international institutions representing the chemical engineering profession globally signed the London Communiqué which pledged *'to make the world a better place for future generations'* (Batterham, 2003).
1997	Joint paper entitled 'Role and Contributions of the Scientific and Technological Community to Sustainable Development', produced by the International Council for Science (ICSU), WFEO, Third World Academy of Sciences (TWAS), the InterAcademy Panel (IAP), and the International Social Science Council (ISSC), (Joint Paper, 2001) following the 1996 World Congress of Engineering Educators and Industry Leaders, organized by UNESCO, UNIDO, WFEO and UATI which devoted considerable attention to education and sustainable development concerns. The World Federation of Engineering Organisations also produced 'The Engineer's Response to Sustainable Development' (WFEO, 2007).
2001	WFEO Model Code of Ethics, which states that, *'Engineers whose recommendations are overruled or ignored on issues of safety, health, welfare, or sustainable development shall inform their contractor or employer of the possible consequences'*. (WFEO, 2009)
2001	6th World Congress on Chemical Engineering: twenty chemical engineering institutions signed the Melbourne Communiqué (2001), a one page document committing each of them to work towards a shared global vision based on sustainable development.
2004	The United States National Academy of Engineering formulated its vision of the Engineer of 2020 (NAE, 2004). This report outlines a number of aspirational goals where it sees the profession taking a more central normative role in society, including facilitating design *'through a solid grounding in the humanities, social sciences, and economics'*, rapidly embracing new fields of endeavour *'including those that require openness to interdisciplinary efforts with nonengineering disciplines such as science, social science, and business'* and taking a lead in the public domain by seeking to influence public policy positively. Critically, the report calls for engineers to be informed leaders in sustainable development and notes that this *'should begin in our educational institutions and be founded in the basic tenets of the engineering profession and its actions'*. It suggests that engineering curricula be reconstituted *'to prepare today's engineers for the careers of the future, with due recognition of the rapid pace of change in the world and its intrinsic lack of predictability'*.

Date	Key Documents Outlining Professional Requirement
2005	The Royal Academy of Engineering (London) published a set of twelve 'Guiding Principles' for engineering for sustainable development (RAE, 2005), in a document which also provided examples and applications for curriculum implementation. The RAE has also sponsored a visiting professors scheme in the UK from 1998 *'to embed the topic of engineering for sustainable development into engineering course and not to create a separate subject'* (RAE, 2005). The 12 Principles are: 1. Look beyond your own locality and the immediate future 2. Innovate and be creative 3. Seek a balanced solution 4. Seek engagement from all stakeholders 5. Make sure you know the needs and wants 6. Plan and manage effectively 7. Give sustainability the benefit of any doubt 8. If polluters must pollute… then they must pay as well 9. Adopt a holistic,'cradle-to-grave' approach 10. Do things right, having decided on the right thing to do 11. Beware cost reductions that masquerade as value engineering 12. Practice what you preach.
2006	International Federation of Engineering Education Societies (IFEES) - a network of 35 engineering organisations including WFEO and FIDIC - formed to establish effective engineering education processes of high quality around the world, to assure a global supply of well-prepared engineering graduates. According to Founder and President Professor Claudio Borri, *'In a few words, the key-question posed by the 21st century global economy to engineering educators and stake-holders is this: How can education in science and technology help to reduce poverty, boost socio-economic development, and take the right decisions for sustainable and environmental compatible development?'* (Borri, 2008)
2006	The Canadian Council of Professional Engineers published a *'National Guideline on Environment and Sustainability'* in 2006 (CCPE, 2006) which outlined nine tenets that professional engineers should adhere to. It states that engineers: 1. Should develop and maintain a reasonable level of understanding, awareness, and a system of monitoring environmental and sustainability issues related to their field of expertise. 2. Should use appropriate expertise of specialists in areas where the professional engineer's knowledge alone is not adequate to address environmental and sustainability issues. 3. Should apply professional and responsible judgment in their environmental and sustainability considerations. 4. Should ensure that environmental planning and management is integrated into all their activities which are likely to have any adverse effects. 5. Should include the costs of environmental protection among the essential factors used for evaluating the economic viability of projects for which they are responsible. 6. Should recognize the value of environmental efficiency and sustainability, consider full life-cycle assessment to determine the benefits and costs of additional environmental stewardship, and endeavour to implement efficient, sustainable solutions. 7. Should engage and solicit input from stakeholders in an open manner, and strive to respond to environmental concerns in a timely fashion. 8. Should comply with regulatory requirements and endeavor to exceed or better them by striving toward the application of best available, cost-effective technologies and

Date	Key Documents Outlining Professional Requirement
	procedures. Should disclose information necessary to protect public safety to appropriate authorities. 9. Should actively work with others to improve environmental understanding and sustainability practices.
2007	The Institution of Chemical Engineers, a signatory body at London and Melbourne, followed through as part of these commitments by drawing up *'A Roadmap for 21st Century Chemical Engineering'* (IChemE, 2007). In practice, this is a type of strategic plan for chemical engineering largely based on moving towards a sustainable future. Each of its six themes, which include 'sustainability and sustainable chemical technology' and 'health, safety, environment and public perception of risk', incorporates strong sustainability threads. Progress on the roadmap was published in 2008 (IChemE, 2008).
2007	Engineers Australia launched a formal sustainability charter in 2007 (Engineers Australia, 2007). This takes a broad view, purposely placing a particular emphasis on the social sphere, an area where engineering has traditionally been weakest (Segalàs et al., 2008). The charter proposes the institution's belief that *'sustainable development should be at the heart of mainstream policy and administration in all areas of human endeavour'*. It also notes that achieving this will not be easy and *'requires a fundamental change in the way that resources are used and in the way that social decisions are made'*. Here an engineering institution is recognising the normative and multi-disciplinary role that engineers can and must play in helping achieve a sustainable global society while also inviting its members to take a larger global view of their roles and perhaps take the lead in finding solutions to relevant issues.
2009	Engineering Council UK (ECUK, 2009) has set out six guidance principles on sustainability for the engineering profession which, it suggests respective professional engineering institutions may wish to use in developing guidance for their members. These are: – Contribute to building a sustainable society, present and future – Apply professional and responsible judgement and take a leadership role – Do more than just comply with legislation and codes – Use resources efficiently and effectively – Seeking multiple views to solve sustainability challenges – Manage risk to minimise adverse impact to people or the environment The third principle provides an implicit admission that the professional codes do not go far enough while the fifth one offers a humble acknowledgement that engineers do not, and cannot have all the answers to the problems arising from our unsustainable societal construct, nor can they alone turn things around. Indeed, they also suggest that engineers should use their influence to help drive future legislation and codes. ECUK clearly envisages a broad, ambitious and integrative role for the 21st Century engineer and suggests; *'the leadership and influencing role of engineers in achieving sustainability should not be under-estimated. Increasingly this will be as part of multi-disciplinary teams that include non-engineers, and through work that crosses national boundaries.'*

Table 4 demonstrates that there has been a general trend from general to specific alongside a progressive heightening of the bar in terms of commitments and expectations over time. This is in line with broader societal context which has seen a progressively stronger emphasis on sustainability and sustainable development as discussed earlier.

4. CODES OF ETHICS

Most PEIs either have a code of ethics or professional conduct which their members are required to adhere to. As an umbrella body, the World Federation of Engineering Organisations has published a model code of ethics (WFEO, 2001). Most national and international professional engineering institutions follw a code of ethics which reads along similar lines. A selection of codes of ethics (Enginers Australia, 2000; IPENZ, 2005; Engineers Ireland, 2009) and the references within them which relate to sustainable development/sustainability are highlighted in Appendix 4.

Among the published codes it is clear that sustainable development/sustainability is envisaged as an area of ethical responsibility for practicing professional engineers. However, rather than the codes of ethics setting sustainability/sustainable development as the very *context* of engineering practice, whereby as Allen at al (2008) envisage *'sustainable engineering ..equates with good engineering',* that is good engineering in both practical and ethical terms, these concepts instead appear more by way of add-on statements that may accompany terms such as 'social', 'environmental', 'safety' and 'health and safety'. This is perhaps suggestive of a larger problem with incremental rather than holistic changes to code of ethics documentation as issues emerge in the profession, though it may also be a function of the relatively recent emphasis on this issue and one which will be addressed among future versions of codes of ethics, as they naturally evolve to reflect evolving PEI policies. At any rate, PEIs such as the UK'S Engineering Council appear to acknowledge this issue when they issue among their six guidance principles on sustainability for the engineering profession that engineers should *'do more than just comply with legislation and codes.'* (ECUK, 2009).

In more general terms, a common theme among these code of ethics statements is also a narrow focus on the individual agent, to the detriment of a broader context, such as a responsibility to act an agent of cultural or societal change. This emphasis on the individual agent has implications in the curriculum as it leads to teaching of ethics based on contrived scenarios which overestimate the influence of individuals within an organisational structure and fails to represent the social, organisational, complexities of real engineering practice (Bucciarelli, 2008). This, Bucciarelli argues, is a minimalist approach which drains inspiration from the profession by failing to meet the engineering student's natural *'positive inclinations to do good'.* Conlon (2008) picks up on this theme and argues that *'A focus on the wider social context is also required if engineers are to contribute to creating a sustainable society.'* In practical terms, Conlon (2010) suggests at this Symposium a broader ethical framework from the field of sociology which engineers could adopt which would envisage both micro and macro issues; for example, acknowledging the responsibility of engineers not just to design components or processes safely, but of at least equal importance, to also consider a culture of safety stemming from *'the organisational culture, the regulatory regime and public policy'*. Such an approach, Conlon argues, could take *'adequate account of the commitment and power of engineers to pursue such goals as safety, sustainability and the enhancement of human welfare.'*

5. ACCREDITATION GUIDELINES

The accreditation process is a powerful instrument in directing the education of engineers and over the longer term, the capacity of the engineering profession.The Royal Academy of Engineering highlight the importance of accreditation as an agent for evolution and change in their report on educating engineers for the 21st Century (RAE, 2007) where they observe that *"the accreditation process for university engineering courses should be proactive in driving the development and updating of course content, rather than being a passive auditing exercise"*.

Accreditation guidelines have evolved as relatively organic entities that continually change to reflect national legislative requirements and strategic policy direction in addition to the ethos of the accrediting PEIs. However, the pace at which accreditation guidelines incorporate various declarations, initiatives, communiqués, charters and policies, appear to be often beset with a significant time lag. This adds to the subsequent considerable time lag between issuing guidelines and widespread implementation throughout programmes, and again between programme implementation and widespread professional practice as highlighted by Desha *et al* (2009). Within this context and given the recent emergence of sustainability related imperatives for engineering education, a significant challenge exists to incorporate such aspects into accreditation requirements in a timely manner. To assist with the ISEE2010 workshop deliberations in this regard, Appendix 5 provides an overview of current accreditation guidelines with respect to sustainability for a number of PEIs globally.

Most of the PEIs considered here come under the mutual recognition umbrella of the International Engineering Alliance's Washington Accord, which seeks (not yet mandatory) adherence to a common set of rules, procedures and performance guidelines (IEA, 2010), as part of the Alliance's expectations for membership. For example, the IEA includes in its guidelines for member institutions a 'graduate profile exemplar'. The strongest and most explicit recommendation with respect to sustainability/sustainable development is that graduates should '*understand the impact of engineering solutions in a societal context and demonstrate knowledge of, and need for, sustainable development*' (IEA, 2007).

However, there is in fact a broad range in outcome requirements among PEIs internationally. This ranges from the most detailed and explicit descriptors based on a learning outcomes approach in countries such as Australia, the UK, Canada, Germany and Ireland, to a more generalised learning outcomes approach which simply provides a number of headings (without further explanatory detail) in countries such as the USA, Japan, Taiwan, etc. There are also accreditation process which appear not to be based on programme learning outcomes at all (e.g. India), to places which appear to have had no accreditation procedure in place at all historically (e.g. China). It seems ironic that areas with the least stringent accreditation requirement produce the highest numbers of engineers. For example, China graduates far more engineers annually than any country (with 600,000 college and university graduates in 2005), while India produces in the region of 350,000-500,000 per annum. By comparison, the USA graduates about 70,000 engineers annually, while Europe produces 100,000 (including 12,000 from the UK) and Australia produces about 6,000 per annum (Desha & Hargroves, 2010).

The accreditation requirements relating to sustainability for institutions in the following countries/international entities are related in Appendix 5, including Ireland, UK, Europe, Germany, France, USA, Canada, India, China, Australia, New Zealand, Japan, Taiwan, and Hong Kong. Specifically, the following terms were sought to identify those accreditation criteria related to EESD:

- sustainability/sustainable development;
- environmental or social issues;
- ethical issues, but only in the context of either of the above;

- multi-disciplinarity; and
- complexity or complex systems, and related (open ended/‘wicked’) problems.

6. CONCLUSIONS AND FUTURE CONSIDERATIONS

This paper began with a discussion of the terminology used surrounding sustainability, sustainable development followed by a review of the literature available on EESD, policies and initiatives of PEIs as well as codes of ethics and accreditation guidelines.

However, the extent of literature on a number of important related topics is lacking. For example, there is an absence of rigorous study on the relative role of the engineering profession in addressing broader issues relating to (un)sustainability such as climate change and water, food and energy supply and demand, or on the importance of interdisciplinary and multidisciplinary action between engineers and others. There are also few academic studies focused on whether shifting expectations necessitate a shift in the knowledge and skills needed to practice as a professional engineer. Furthermore, there appear to be no studies comparing success in student recruitment or departmental viability for those departments who incorporate EESD against those who don’t. There is also a lack of data assessing relationships between career success for engineers with and without sustainability related capabilities. In such a rapidly emerging field these ‘gaps’ in academic literature are problematic, but do not prevent further exploration of the topic.

In conclusion, despite the growth in literature on the need for EESD, there has not yet been a rigorous global review of this discipline undertaken by any single organisation or collaboration. Conference themes and journal topics have tended to focus on issues affecting the ability of engineering education to be changed (i.e. organisational, resourcing, funding, timeframe and content issues), rather than the extent to which the curriculum has changed. Within EESD literature, the most prolific papers have been on the topic of single champions or teams discussing individual initiatives in the subject area of EESD. Some papers have documented the success of strategically embedding case studies and flagship courses (predominantly in first year, and at post-graduate level), and few papers have discussed methods to integrate sustainability theory, understanding and application across programs and across disciplines.

Within this context, it is hoped that the ISEE2010 Delegate Workshop, in conjunction with Professional Institutions’ Forum at ISEE2010 can play a significant role in exploring the issues involved, and perhaps move the discussion forward. As an ISEE2010 keynote speaker David Wood in his opening plenary address to the World Congress of Chemical Engineering in Montreal in 2009 (Wood, 2009), exhorted:

> *‘If our role is to address the challenges of the 21st Century (e.g. ‘The Roadmap’), it is essential that our undergraduate programs must be reformed – NOT MORE OF THE SAME.’*

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APPENDIX 1 LITERATURE REPORTING ON EESD INTERNATIONALLY

There is a growing volume of engineering education literature on the topic of what EESD should comprise within the engineering curriculum, including content and pedagogical practices. Over the last 10 years discourse has moved from attempting to understand the term 'sustainability' as it relates to environmental education, social science, higher education (for example authors such as Sauvé,[1] Fien,[2] Leal,[3] Sterling,[4] Corcoran and Wals,[5] Parkin *et al*[6], Cortese,[7] Blewitt and Cullingford,[8]and Dawe *et al*[9]), and the engineering profession (for example Jansen,[10] Mulder,[11,12] Ferrer-Balas *et al*[13], Holmberg *et al*[14]), to attempting to understand what knowledge and skills graduate engineers should be equipped with (for example Carroll,[15] Cortese,[16] Crofton,[17] Ashford,[18] Azapagic *et al*,[19,20] McKeown *et al*,[21] Pritchard *et al*[22] and Allenby *et al*[23]), how EESD should be taught with regard to pedagogical practices (for example Timpson *et al*[24] on tips for integration, Newman and Fernandez[25] who discuss institutionalising such curriculum renewal, Steinemann[26] and Lehmann *et al*,[27] who write about problem based learning, and Crawley *et al*[28] who discussed the need for sustainable development to form a framework within which engineering education needs to be rethought), and the larger education agenda (for example Rowe who discusses policy direction,[29] Stephens and Graham[30] who discuss research needs, Steinfeld and Takashi[31] who discuss the challenge of trans-disciplinarity, and Holdsworth *et al*[32] who discuss the need for professional development for ESD).

Internationally, a number of professional organisations have also undertaken reviews on the topic, such as the 2005 American National Academy of Engineering (NAE) report on educating the engineer of 2020,[33] the 2006 UNESCO workshop on Engineering Education for Sustainable Development,[34] the 2007 UK Royal Academy of Engineering (RAE) report on educating engineers for the 21st Century,[35] the Higher Education funding Council for England (HEFCE) *Strategic Review of Sustainable Development in Higher Education in England*,[36] and the Chinese Academy of Engineering.[37] There are also numerous authors writing about local experiences in trying to embed EESD within their own universities around the world, as highlighted in Table A1.

Table A1. Examples of papers on EESD initiatives

Country/ Region	Example author and institution details
Europe	Kamp[38] and Mulder[39] in Netherland's Delft University; Lundqvist *et al*[40] in Sweden's Chalmers University; Fenner *et al*[41] in the UK's Cambridge University; Humprhies-Smith[42] in the UK's Bournemouth University; Lozano[43] in Wales' Cardiff University; Fletcher *et al*[44] in England's Aston University; Ferrer-Balas *et al*[45] in Spain's UPC.
North America	Allenby *et al*[46] national overview; Epstein *et al*[47] in the Massachusetts Institute of Technology; Mihelcic *et al*[48] in Michigan Technical University;
South America	Lozano-Garcia *et al*[49] in ITESM Monterrey; Wright *et al*[50] writing about the collaboration between Michigan University and Chile's University of Concepción
Asia	Onuki and Takashi[51] in Japan's University of Tokyo; Uwasu *et al*[52] in Japan's Osaka University; Kuangdi[53] in a Chinese national overview.
Africa	Olorunfemi and Dahunsi[54] in Lagos State Polytechnic and the University of Ibadan, Nigeria; Ramjeawon[55] in the University of Mauritius.
Australia	Davis and Savage[56] in Queensland University of Technology, Goh[57] in the University of Southern Queensland, Bryce *et al*[58] in the University of Technology Sydney, Mitchell[59] in the University of Sydney; Carew and Therese[60] in the University of Wollongong; Koth and Woodward[61] in the University of South Australia; Daniell and Maier[62] in the University of Adelaide; Carew and Lindsay[63] in the University of Tasmania and Curtin University;[64] Mann and Smith in computing engineering.[65]

Within the literature highlighted in Table A1, there are many references to ensuring that engineers have a good understanding of: global systems and ecosystem principles; economic, social and environmental risks; impacts and opportunities associated with their engineering solutions; and knowledge and skills in sustainable development related tools and technologies. Further to this, authors such as Pérez-Foguet *et al*[66] also discuss the need to incorporate developing country issues into engineering studies, and authors such as Boyle,[67] Steinfeld and Takashi,[68] Kumazawa *et al*,[69] and Mihelcic *et al*[70] present an emerging field of 'Sustainability Science' as a way to describe what should be taught in EESD, which incorporates the notion of transdisciplinarity, and which integrates industrial, social, and environmental processes in a global context.[71]

Given the broad spectrum of conceptualizations regarding sustainability, sustainable development and EESD, there is unsurprisingly a very broad range of conceptualization of what embedding such content into the engineering curriculum might mean and indeed how this is applied in practice. With this in mind, we now consider the extent to which progress has been made, before proceeding to examine the type of accreditation and other requirements being established by PEIs.

APPENDIX 2 SUMMARY OF KEY SURVEYS ON THE STATE OF EESD

Year	Survey	Brief Description
1998	World Engineering Partnership for Sustainable development	Questionnaire circulated to national members of WFEO to provide an improved benchmark. Conclusion: No strong or consistent approach to environment and sustainable development in engineering education. On a country average, not much more than 10 per cent of time in 10 per cent of courses is devoted to these aspects.[72]
2000-2002	University of Surrey (UK) and University of Melbourne (Australia)	Survey of a sample of international engineering students on their level of knowledge and understanding of sustainable development; the first of its type.[73] Conclusion: (21 respondents from 40 invitees) The level of sustainable development knowledge is not satisfactory, and significant knowledge gaps exist within the curriculum.[74]
2002	Royal Melbourne Institute of Technology	Twenty-one Australian universities invited to participate in a survey on the status of ESD in these institutions. Conclusion: (from a quarter of invitees) Few universities are engaged in such education for a wide range of their students. In some universities more students of particular disciplines are gaining exposure. However, there are clear barriers to the introduction and expansion of sustainability education.[75]
2006	Chalmers University of Technology, Delft Technical University, Technical University of Catalonia, Alliance for Global Sustainability	The Observatory assessed the status of EESD in European Higher Education, benchmarking 51 European Universities (survey), against examples from outside Europe. Conclusion: To-date there is no European University that shows sufficient progress in EESD to be considered an inspiration.[76]
2007	Forum for the Future's Engineers of the 21st Century Programme	499 young engineers (online) who had graduated between 1997 and 2005 surveyed regarding sustainability literacy.[77] Conclusion: 40 percent perceived their university lecturers had inadequate knowledge of sustainability. 30 percent perceived their lecturers had a positive to passionate attitude about ESD.
2007	National Framework for Energy Efficiency[78]	National survey on the state of engineering education in Australia, within the sub-topic of energy efficiency education. Conclusion: The state of education for EE in Australian engineering education is currently highly variable and ad hoc across universities and engineering disciplines. Key issues for educators included perceived course overload, and lack of time for professional development or to prepare new content.
2007-2008	US Center for Sustainable Engineering	Benchmarking survey on the extent of sustainable engineering education within 1,368 engineering departments (or the equivalent), with just over one fifth of the invited 364 American universities and colleges participating.[79] Conclusion: The engineering education community is now at a critical juncture. To-date, there has been a significant level of 'grass-roots' activities but little structure or organisation. The next step will be for engineering accreditation bodies to think critically about what should or should not be included.[80]
2008	Chalmers University of Technology, Delft Technical University, UPC, Alliance for Global Sustainability.	Second survey by *The Observatory*[81] initiative. Of the 57 universities participating in the 2008 survey, most had not participated in the 2006 survey, making it difficult to directly compare results of the reports. Conclusion: A growing number of institutions from European countries are actively engaged in sustainability activities.

APPENDIX 3. EXAMPLES OF DECLARATIONS PROMOTING ESD

Date	Declaration	Brief Description
1990	Talloires Declaration	The Talloires Declaration is a ten-point action plan for colleges and universities committed to promoting education for sustainability and environmental literacy in teaching, research, operations and outreach at colleges and universities.[82] The role of the university is defined as, *'Universities educate most of the people who develop and manage society's institutions. For this reason, universities bear profound responsibilities to increase the awareness, knowledge, technologies, and tools to create an environmentally sustainable future'*.[83]
1992	Agenda 21	The need for education to play a key role in addressing the challenge of sustainable development was articulated within the global community two years later at the Rio Earth Summit in 1992, with its action plan *Agenda 21*[84] calling for education. This was acknowledged in a range of national planning documentation around the world.[85]
1997	Thessaloniki Declaration	This declaration was made unanimously by 83 countries, relating to education and public awareness for sustainability [86]
1998	World Declaration	UNESCO World Conference on Higher Education produced the *World Declaration on Higher Education in the Twenty-First Century: Vision and Action*, which stated that, *'Without adequate higher education and research institutions providing a critical mass of skilled and educated people, no country can ensure genuine endogenous and sustainable development'*.[87]
2000	Earth Charter	The United *Nations Earth Charter* released in 2000, also provided a general statement of ethics and values for a sustainable future.[88]
2001	Lüneburg Declaration	This declaration was adopted by the GHESP partners (IAU, ULSF, Copernicus Campus and Unesco), on the occasion of the International COPERNICUS Conference, titled 'Higher Education for Sustainability Towards the World Summit on Sustainable Development (Rio+10)'.[89]
2002	Ubuntu Declaration	At the 2002 World Summit on Sustainable Development, this declaration was created for all levels of education, focusing on the need for education and science and technology for sustainable development.[90]
2002	Ubuntu Declaration	At the 2002 World Summit on Sustainable Development, this declaration was created for all levels of education, focusing on the need for education and science and technology for sustainable development.[91]

APPENDIX 4 EXTRACTS FROM SELECTED PEI CODES OF ETHICS

The World Federation of Engineering Organizations has published a model code of ethics (WFEO, 2001). The most explicit parts on the issue of sustainability contained within it include the following excerpts:

‘Issues regarding the environment and sustainable development know no geographical boundaries. The engineers and citizens of all nations should know and respect the environmental ethic.…

II. PRACTICE PROVISION ETHICS.

Professional engineers shall [among other requirements]:
- *hold paramount the safety, health and welfare of the public and the protection of both the natural and the built environment in accordance with the Principles of Sustainable Development;*
- *be aware of and ensure that clients and employers are made aware of societal and environmental consequences of actions or projects and endeavor to interpret engineering issues to the public in an objective and truthful manner; …*

III. ENVIRONMENTAL ENGINEERING ETHICS
Engineers, as they develop any professional activity, shall:
- *try with the best of their ability, courage, enthusiasm and dedication, to obtain a superior technical achievement, which will contribute to and promote a healthy and agreeable surrounding for all people, in open spaces as well as indoors;*
- *strive to accomplish the beneficial objectives of their work with the lowest possible consumption of raw materials and energy and the lowest production of wastes and any kind of pollution;*
- *discuss in particular the consequences of their proposals and actions, direct or indirect, immediate or long term, upon the health of people, social equity and the local system of values;*
- *study thoroughly the environment that will be affected, assess all the impacts that might arise in the structure, dynamics and aesthetics of the ecosystems involved, urbanized or natural, as well as in the pertinent socioeconomic systems, and select the best alternative for development that is both environmentally sound and sustainable;*
- *promote a clear understanding of the actions required to restore and, if possible, to improve the environment that may be disturbed, and include them in their proposals;*
- *reject any kind of commitment that involves unfair damages for human surroundings and nature, and aim for the best possible technical, social, and political solution;*
- *be aware that the principles*
- *bases poses a threshold of sustainability that should not be exceeded …*

Sustainable Development and Environment ...
Engineers shall strive to enhance the quality of the biophysical and socioeconomic urban environment and the one of buildings and spaces and to promote the principles of sustainable development. Engineers shall seek opportunities to work for the enhancement of safety, health, and the social welfare of both their local community and the global community through the practice of sustainable development. Engineers whose recommendations are overruled or ignored on issues of safety, health, welfare, or sustainable development shall inform their contractor or employer of the possible consequences.’

Codes of Ethics by national and international PEIs follow much along the same lines. For example, the Engineers Australia requires (tenet 6 of 9) that;

> *‘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’.*

Moreover, Engineers Ireland Code of Ethics includes three broad headings, the second of which is entitled ‘Environmental & Social Obligations’. Five such obligations are mentioned. They require that *‘members shall:*

- *at all times be conscious of the effects of their work on the health and safety of individuals and on the welfare of society. While acting as designers, operators or managers on projects, members shall strive to eliminate risks to health and safety during all project stages. Members shall also undertake to minimise or eliminate any adverse impact on the natural environment arising from the design and execution of all project work that they are engaged in.*
- *promote the principles and practices of sustainable development and the needs of present and future generations.*
- *strive to accomplish the objectives of their work with the most efficient consumption of natural resources which is practicable economically, including the maximum reduction in energy usage, waste and pollution.*
- *promote the importance of social and environmental factors to professional colleagues, employers and clients with whom they share responsibility and collaborate with other professions to mitigate the adverse impacts of their common endeavours.*
- *foster environmental awareness within the profession and among the public.*

The Code of Ethics for New Zealand engineers (IPENZ, 2005) includes guidelines under five headings including *‘Sustainable Management and Care of the Environment’*, which states that;

> *‘members shall recognise and respect the need for sustainable management of the planet's resources and endeavour to minimise adverse environmental impacts of their engineering activities for both present and future generations’*

and another under *‘Commitment to Community Well-being’* which requires that;

> *‘members shall recognise the responsibility of the profession to actively contribute to the well-being of society and, when involved in any engineering activity shall, endeavour to identify, inform and consult affected parties.’*

Commitments under the former heading include having due regard to;

> *‘using resources efficiently, endeavouring to minimise the generation of waste and encouraging environmentally sound reuse, recycling and disposal, recognising adverse impacts of engineering activities on the environment and seeking to avoid or mitigate them’* and *‘recognising the long-term imperative of sustainable management’.*

APPENDIX 5 EXTRACTS FROM SELECTED PEI ACCREDITATION GUIDELINES

Table of Contents

5.1. Ireland – Engineers Ireland

Extracts from accreditation criteria for engineering education programmes (Engineers Ireland, 2007).

At the professional (masters) level there are seven required programme outcomes that graduates must possess:

a) Knowledge and understanding of the mathematics, sciences, engineering sciences and technologies underpinning their branch of engineering.
b) The ability to identify, formulate, analyse and solve engineering problems.

Graduates should, *inter alia*, be able to;
(i) integrate knowledge, handle complexity and formulate judgements with incomplete or limited information;
(iii) identify and use appropriate mathematical methods for application to new and ill-defined engineering problems;

c) The ability to design components, systems or processes to meet specific needs.

Graduates should have, *inter alia*;
(i) knowledge and understanding of design processes and techniques and the ability to apply them in unfamiliar situations;
(ii) ability to apply design methods to unfamiliar, ill-defined problems, possibly involving other disciplines;
(iii) ability to investigate and define a need and identify constraints including environmental and sustainability limitations, health and safety and risk assessment issues;

d) The ability to design and conduct experiments and to apply a range of standard and specialised research tools and techniques.

Graduates should, *inter alia*, be able to;
iv) incorporate aspects of engineering outside their own discipline and to consult and work with experts in other fields;

e) Understanding of the need for high ethical standards in the practice of engineering, including the responsibilities of the engineering profession towards people and the environment.

Graduates should have, *inter alia*;
(i) ability to reflect on social and ethical responsibilities linked to the application of their knowledge and judgements;
(ii) knowledge and understanding of the social, environmental, ethical, economic, financial, institutional and commercial considerations affecting the exercise of their engineering discipline;
(iii) knowledge and understanding of the health, safety and legal issues and responsibilities of engineering practice and the impact of engineering solutions in a societal and environmental context;
(iv) knowledge and understanding of the importance of the engineer's role in society and the need for the highest ethical standards of practice;
(v) knowledge and understanding of the framework of relevant legal requirements governing engineering activities, including personnel, environmental, health, safety and risk issues.

f) The ability to work effectively as an individual, in teams and in multi-disciplinary settings, together with the capacity to undertake lifelong learning.

Graduates should have, *inter alia*;

(i) ability to recognise and make use of the interactions between the engineering technologies and the technologies associated with other disciplines and professions;
(ii) ability to consult and work with experts in various fields in the realisation of a product or system;
(vi) knowledge and understanding of concepts from a range of areas outside engineering.

g) The ability to communicate effectively with the engineering community and with society at large.

In addition Engineers Ireland outline six required ‘Programme Area Descriptors’. Programme Area descriptors outline how each Programme Area, through the learning outcomes of its constituent modules, can contribute to the achievement of the Programme Outcomes by the engineering graduate. The Programme Areas are:

(a) Sciences and Mathematics

(b) Discipline-specific Technology

(c) Software and Information Systems

(d) Creativity and Innovation

In both research and design, students should have the opportunity to be involved in multi-disciplinary projects.

(e) Engineering Practice

Students need to be familiar with general engineering practice and with the particular operational practices of their discipline. Related to this is responding to real life situations and day-to-day management of complex engineering projects – supervising others, dealing with technical uncertainty and having awareness of codes of practice and the regulatory framework.

(f) Social and Business Context

Engineering is directed to developing, providing and maintaining infrastructure, goods, systems and services for industry and the community. Programmes need to develop an awareness of the social and commercial context of the engineer’s work. This includes an understanding of issues relating to today’s multi-cultural workforce, of socio-technology and of the constraints on technological developments imposed by health and safety, the environment, codes of practice, politics, the law and financial viability, management issues and the means by which the various risks may be assessed and managed. Students should be made aware of the various methods for the assessment of quality and fitness for purpose of engineering products and systems, and understand how to achieve these attributes in design and development. They should be given ample opportunity to analyse and discuss the ethical consequences of their decisions.

Society expects professional behaviour from its professional engineers and therefore programmes should enable students to become familiar with the expectations and standards inherent in professional codes of conduct.

5.2. United Kingdom

5.2.1. UK Engineering Council

Extracts from the UK Standard for Professional Engineering Competence (Engineering Council, 2010)

In the United Kingdom (UK), Engineering Council is responsible for the UK register of Chartered Engineers as well as Incorporated Engineers and Engineering Technicians. It prescribed accreditation competences are therefore incorporated by all the discipline specific institutions which come under its remit. It requires fours sets of general learning outcomes for all (BEng and MEng) graduates; Knowledge and Understanding, Intellectual Abilities, Practical skills, General transferable skills.

In addition, professional (MEng) graduates should display:

The ability to develop, monitor and update a plan, to reflect a changing operating environment

The ability to monitor and adjust a personal programme of work on an on-going basis, and to learn independently

An understanding of different roles within a team, and the ability to exercise leadership

The ability to learn new theories, concepts, methods etc in unfamiliar situations.

In addition the Engineering Council requires a range of specific learning outcomes of all graduates under five headings:

1. Underpinning science and mathematics, and associated engineering disciplines, as defined by the relevant engineering institution
2. Engineering Analysis
3. Design

   Design is the creation and development of an economically viable product, process or system to meet a defined need. It involves significant technical and intellectual challenges and can be used to integrate all engineering understanding, knowledge and skills to the solution of real problems. Graduates will therefore need the knowledge, understanding and skills to:

   - *Investigate and define a problem and identify constraints including environmental and sustainability limitations, health and safety and risk assessment issues;*
   - *Understand customer and user needs and the importance of considerations such as aesthetics;*
   - *Identify and manage cost drivers;*
   - *Use creativity to establish innovative solutions;*
   - *Ensure fitness for purpose for all aspects of the problem including production, operation, maintenance and disposal;*
   - *Manage the design process and evaluate outcomes.*
4. Economic, social, and environmental context

   - *Knowledge and understanding of commercial and economic context of engineering processes;*
   - *Knowledge of management techniques which may be used to achieve engineering objectives within that context;*
   - *Understanding of the requirement for engineering activities to promote sustainable development;*
   - *Awareness of the framework of relevant legal requirements governing engineering activities, including personnel, health, safety, and risk (including environmental risk) issues;*
   - *Understanding of the need for a high level of professional and ethical conduct in engineering.*
5. Engineering Practice (including):
   - *Ability to work with technical uncertainty.*
   - *A thorough understanding of current practice and its limitations, and some appreciation of likely new developments (only for professional (MEng) level graduates)*

5.2.1 Institution of Chemical Engineers (IChemE)

Extracts from A guide for university departments and assessors, for accreditation of chemical engineering degrees (IChemE, 2009)

The IChemE accredits degrees which fulfil the competencies for Chartered (i.e. professional) Engineer as required by the UK Engineers Council. In its accreditation procedures, the IChemE outlines four general learning outcomes (as per Engineering Council): Knowledge and understanding (They must have an appreciation of the wider engineering context. They must appreciate the social, environmental, ethical, safety, economic and commercial considerations affecting the exercise of their engineering judgement.), Intellectual abilities (They must be able to comprehend the ‘broad picture’ and thus work with an appropriate level of detail.), Practical skills and General transferable skills.

In addition, seven areas of learning must be clearly taught in all programmes (BEng/MEng) seeking IChemE accreditation (with an 8th required for MEng programmes):

1. Underpinning mathematics and science
2. Core chemical engineering - They must be able to apply chemical engineering methods to the analysis of complex systems within a structured approach to safety.
3. Engineering practice
4. Design practice
5. Embedded learning (sustainability, SHE)* Students must acquire the knowledge and ability to handle broader implications of work as a chemical engineer. These include sustainability aspects; safety, health, environmental and other professional issues including ethics; commercial and economic considerations etc.

   Graduates must be able to calculate and explain process, plant and project economics. They should also appreciate the need for high ethical and professional standards and understand how they are applied to issues facing engineers. They must be aware of the priorities and role of sustainable development. They must be aware of typical legal requirements on personnel, processes, plants and products relating to health, safety and environment. It is expected that this material is consistently built upon and themes reinforced throughout the degree.

6. Embedded learning (general transferable skills) - Unlike all other categories, no minimum requirement in quantity is needed – rather ‘sufficient demonstration’ is required.
7. Complementary subjects
8. Advanced chemical engineering (depth, breadth, practice and design) (MEng only)

5.2.2 Institution of Mechanical Engineers (IMechE)

Extracts from the Institution of Mechanical Engineers Academic Accreditation Guidelines (IMechE, 2009)

The Institution of Mechanical Engineers specify five general learning outcomes for programmes. These are:

1. Underpinning Science and Mathematics and associated engineering disciplines
2. Engineering Analysis
3. Design
   - *Investigate and define a problem and identify constrains including environmental and sustainability limitations, health and safety and risk assessment issues*
   - *Ensure fitness for purpose for all aspects of the problem including production, operation, maintenance and disposal*
4. Economic, social and environmental context
   - *Understanding of the requirement for engineering activities to promote sustainable development*
   - *Awareness of the framework of relevant legal requirements governing engineering activities, including personnel, health, safety, and risk (including environmental risk) issues.*
5. Engineering Practice

In addition, the IMechE document lists ten qualification descriptors (‘QAA Qualification Descriptor for Masters degrees’) as ‘principal reference points for Masters degrees’ as stated by the Engineering Council ‘UK-SPEC publication’. These include the requirement that ‘Applicants will be able to:

> *Q5 Deal with complex issues both systematically and creatively, make sound judgements in the absence of complete data, and communicate their conclusions clearly to specialist and non-specialist audiences and will have the qualities and transferable skills necessary for employment requiring:*
>
> *Q9 Decision-making in complex and unpredictable situations*

5.3. Europe - FEANI

Extracts from the EUR-ACE Framework Standards for the Accreditation of Engineering Programmes (FEANI, 2009)

FEANI, the European Federation of National Engineering Associations, runs the EUR-ACE accreditation standard. A core of national associations in six jurisdictions currently adopt this framework, in France, Germany, Ireland, Portugal, Russia and the UK, though new national associations are reported to be soon about to join the system, which can also include in principle, non-European countries (Augusti, 2008).

The framework applies to both first (bachelors) and second (professional, masters) degrees and has six programme outcomes:

1. Knowledge and Understanding
2. Engineering Analysis

Second Cycle graduates should have the ability to solve problems that are unfamiliar, incompletely defined, and have competing specifications

3. Engineering Design

Graduates should be able to realise engineering designs consistent with their level of knowledge and understanding, working in cooperation with engineers and non-engineers. The designs may be of devices, processes, methods or artefacts, and the specifications could be wider than technical, including an awareness of societal, health and safety, environmental and commercial considerations.

Second Cycle graduates should have:

- *an ability to use their knowledge and understanding to design solutions to unfamiliar problems, possibly involving other disciplines*
- *an ability to use creativity to develop new and original ideas and methods*
- *an ability to use their engineering judgement to work with complexity, technical uncertainty and incomplete information*

4. Investigations
5. Engineering Practice - Graduates should be able to recognise the wider, non-technical implications of engineering practice, ethical, environmental, commercial and industrial

First Cycle graduates should have:

- *an awareness of the non-technical implications of engineering practice*
- *Second Cycle graduates should have:*
- *the ability to integrate knowledge from different branches, and handle complexity*
- *a knowledge of the non-technical implications of engineering practice.*

6. Transferable Skills

First Cycle graduates should be able to demonstrate awareness of the health, safety and legal issues and responsibilities of engineering practice, the impact of engineering solutions in a societal and environmental context, and commit to professional ethics, responsibilities and norms of engineering practice.

5.4. Germany - ASIIN

Excerpts of the requirements and procedural principles for the Accreditation and Reaccreditation of Bachelor's and Master's Degree Programmes in Engineering, Architecture, Informatics, the Natural Sciences and Mathematics (ASIIN, 2008)

ASIIN is the German institution responsible for examining and certifying Bachelor's and Master's programmes in engineering, in informatics/computer science, in the natural sciences and in mathematics. A learning outcomes based approach is undertaken at both bachelors and masters level.

Learning Outcomes – Bachelor's Degree Programmes in the fields of engineering, the natural sciences, informatics, architecture and mathematics. Specialist Competences include:

- *are capable of successfully conducting analytical or synthetic and developmental tasks, while taking into account scientific, technical, social, environmental, economic and societal ancillary conditions or standards, and using appropriate methods and suitable work techniques*
- *understand the effects their activities have on the environment and recognise the need for sustainable development*

Social Competences include:

- *are aware of the social and ethical responsibilities that underpin their actions, and of the professional ethical principles and standards that apply to their chosen discipline*

Learning Outcomes – Master's Degree Programmes in the fields of engineering, the natural sciences, informatics, mathematics and architecture have, in addition:

Specialist Competences

- *deepened the specialist and interdisciplinary knowledge they acquired during their first degree programme conferring a professional qualification, and / or broadened this knowledge through further methodological and analytical approaches*
- *gained the ability to formulate solutions to complex problems and tasks in a scientific context or for use in industry or society, and to critically analyse and further refine these solutions. Complex problems and tasks of this type exhibit the following characteristics:*
  - *their solution requires an analytical approach based on underlying principles they involve a broad range of sometimes conflicting factors, as well as different groups who are either affected by or have an interest in them they require different potential solutions to be weighed up they are uncommon in the relevant scientific or technical context, and fall outside pre-defined standards and paradigm solutions*
  - *acquired the skill of recognising future problems, technologies and scientific developments due to the depth and breadth of the competences they have mastered, and of subsequently including them in their work.*

5.5. France - Commission des Titres d'Ingénieur (CTI)

Guide d'Autoévaluation des Formations d'Ingénieurs (CTI, 2006). This document elaborates on the Standards-Cadre criteria defined by EUR-ACE, and develops, where applicable, the orientation proposed by the CTI.

5.6. USA - ABET

Excerpts of engineering programs effective for evaluations during the 2010-2011 accreditation cycle (ABET, 2009)

A total of eleven Program Outcomes are listed under ‘Criterion 3’. Those of relevance here are listed;

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

(d) an ability to function on multidisciplinary teams

(f) an understanding of professional and ethical responsibility

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

No further elaboration on the program outcomes is offered.

5.7. Canada - Engineers Canada/Ingénieurs Canada

Excerpts from accreditation criteria and procedures/Normes et procédures d’agrément (Engineers Canada/Ingénieurs Canada, 2009)

Engineers Canada employ twelve ‘Graduate Attributes’. Of most relevance is:

Impact of engineering on society and the environment: An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.

The criteria include two other attributes which involve handling complexity;

Investigation: An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.

Design: An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.

5.8. Australia – Engineers Australia

Excerpts from Engineers Australia national generic competency standards – stage 1 Competency standard for professional engineers (2006)

Engineers Australia requires that graduates possess competencies under three broad headings; Knowledge Base, Engineering Ability and Professional Attributes (Engineers Australia, 2006). Engineers Australia provide a requirement for the incorporation of sustainability and related issues to a level of detail and extent that is perhaps unmatched by any of the other institutions considered here. Relevant competencies are outlined below.

ENGINEERING ABILITY (6 sub headings, including:)

PE2.1 Ability to undertake problem identification, formulation, and solution

a. *Ability to identify the nature of a technical problem, make appropriate simplifying assumptions, achieve a solution, and quantify the significance of the assumptions to the reliability of the solution*

b. *Ability to investigate a situation or the behaviour of a system and ascertain relevant causes and effects*

c. *Ability to address issues and problems that have no obvious solution and require originality in analysis*

d. *Ability to identify the contribution that engineering might make to situations requiring multidisciplinary inputs (see also PE2.2 and PE2.3) and to recognise the engineering contribution as one element in the total approach*

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

a. *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*

b. *Appreciation of the imperatives of safety and of sustainability, and approaches to developing and maintaining safe and sustainable systems*

c. *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*

d. *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

a. *Ability to engage with ill-defined situations and problems involving uncertainty, imprecise information, and wide-ranging and conflicting technical and nontechnical factors*

b. *Understanding of the need to plan and quantify performance over the lifecycle of a project or program, integrating technical performance with social, environmental and economic outcomes*

c. *Ability to utilise a systems-engineering or equivalent disciplined, holistic approach to incorporate all considerations*

d. *Understanding of the process of partitioning a problem, process or system into manageable elements, for purposes of analysis or design; and of recombining these to form the whole, with the integrity and performance of the overall system as the paramount consideration*

e. *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*

f. *Ability to comprehend, assess and quantify the risks in each case and devise strategies for their management*

g. *Ability to select an optimal approach that is deliverable in practice, and justify and defend the selection*

h. *Understanding of the importance of employing feedback from the commissioning process, and from operational performance, to effect improvements*

PE2.4 Proficiency in engineering design

c. *Experience in personally conducting a major design exercise to achieve a substantial engineering outcome to professional standards, demonstrating capacity to (among others):*
    - *ensure that the chosen solution maximises functionality, safety and sustainability, and identify any possibilities for further improvement develop and complete the design or plan using appropriate engineering principles, resources, and processes*
    - *ensure integration of all functional elements to form a coherent, selfconsistent system; check performance of each element and of the system as a whole*

PROFESSIONAL ATTRIBUTES (7 sub headings, including:)

PE3.3 Capacity for creativity and innovation

a. *Readiness to challenge engineering practices from technical and nontechnical viewpoints, to identify opportunities for improvement*

b. *Ability to apply creative approaches to identify and develop alternative concepts and procedures*

c. *Awareness of other fields of engineering and technology with which interfaces may develop, and openness to such interactions*

d. *Propensity to seek out, comprehend and apply new information, from wide range of sources*

e. *Readiness to engage in wide-ranging exchanges of ideas, and receptiveness to change*

5.9. New Zealand - Engineers New Zealand (IPENZ)

Excerpts from Graduate Competency Profiles (IPENZ, 2009) - Requirements for initial academic education for Professional Engineers (IPENZ, 2009a)

IPENZ requires among graduates of accredited programs eleven technical foundations, including:

- *Problem Solving: Able to formulate and solve models which predict the behaviour of part or all of: Complex engineering systems using first principles of the fundamental engineering sciences and mathematics*

- *Design and Synthesis: Able to synthesise and demonstrate the suitability and efficacy of solutions to part or all of: Complex engineering problems*
- *Management: Understands the accepted methods of dealing with uncertainty (such as safety factors) and the limitations of applicability of methods of design and analysis by being able to: Identify, evaluate and manage physical risks in complex engineering problems*

Furthermore, the document provides a definition of ‘complex engineering problems’:

Complex engineering problems means engineering problems which cannot be resolved without in-depth engineering knowledge and having some or all of the following characteristics:

- *Involve wide-ranging or conflicting technical, engineering and other issues*
- *Have no obvious solution and require originality in analysis*
- *Involve infrequently encountered issues*
- *Are outside problems encompassed by standards and codes of practice for professional engineering*
- *Involve diverse groups of stakeholders with widely varying needs*
- *Have significant consequences in a range of contexts*

Moreover, general responsibilities of an engineer are listed:

General responsibilities of an engineer include:

- *Social responsibilities including ethics, health and safety and other legislation*
- *Cultural responsibilities including, in New Zealand, the Treaty of Waitangi*
- *Environmental responsibilities including the need for sustainable development and design and legislative responsibilities*

In an accompanying document to ‘Graduate Competency Profiles’, thirteen curriculum requirements are listed, one of which is sustainability (IPENZ, 2009a):

Sustainability - Material on sustainability should be integrated throughout the curriculum, so students can consider the impacts of design upon society, nations and the environment. A systems approach is encouraged, including interdisciplinary teams, to teach sustainable engineering concepts.

The provider is required to demonstrate that the curriculum includes:

- *appropriate coverage of sustainable technologies and sustainable development methodologies.*
- *integrated consideration of the social and environmental effects of students’ future engineering activities.*

5.10. China - China Association for Science and Technology (CAST)

Although China is the largest producer of engineering graduates in the world, it has not historically had a formalised engineering programme accreditation system. In 2005 a number of Chinese government departments and relevant agencies, including the Ministry of

Personnel, the Ministry of Education, the Ministry of Construction, the Chinese Academy of Engineering and the China Association for Science and Technology, established a National Coordination Group for Reform of the Engineer System (CAST, 2007). This group was set up to research China's engineering framework and hence propose a plan of reform. It was also charged with taking the initiative to promote international mutual recognition of engineering qualifications with international peers.

The China Association for Science & Technology (CAST) is a national umbrella professional and academic organization, incorporating some 64 engineering societies. For example, among other initiatives, as part of an overall ultimate ambition to join the Washington Accord, it has overseen international links 'in mutual recognition of engineers and engineering educational programs' with other accreditation bodies since the 1990's including those between China Mechanical Engineering Society (CMES) and the UK based institutions, The Institution of Engineering & Technology (IET) and the Institution of Mechanical Engineers (IMechE), the Hong Kong Institution of Engineers (HKIE) and the American Mechanical Engineering Society (CAST, 2007) .

Since the end of 2005, there has been a move to establish an accreditation system for China's engineering programmes, and four disciplines were selected as bases for pilot accreditation; electrical engineering and automation, mechanical engineering and automation, chemical engineering and technology and computer engineering (CAST, 2007). Professor David Wood, who is advisor on IChemE accreditation and curricula reform to nine chemical engineering departments in China, has suggested that the changes being made in China 'are bringing programs to those of the mid to late 20th Century' [in the rest of the (Washington Accord) world], while issues such as 'safety and sustainable development are mostly neglected in Asia' (Wood, 2009). However, Wood points out in his keynote address to this Symposium (Wood, 2010) that China produces more chemical engineering graduates than the entire rest of the world, and wonders 'what hope is there for the rest of us', if as has been suggested by others (Cussler (2005), Armstrong (2006)), it is valid to say that lead countries (in terms of curricula content and structure) such as the USA and the UK are 30-40 years out of date?

5.11. India - National Board of Accreditation (NBA)

Excerpts of evaluation guidelines for NBA Accreditation of Undergraduate Engineering Programmes (NBA, 2009)

The NBA's accreditation procedures involve the allocation of 1000 points to programmes seeking accreditation. A learning outcomes approach does generally not appear to be applied, with just 100 of the available 1000 points based on 'Programme Educational Objectives'. Even within these, there are no explicitly specified objectives; programs are simply required to: '*Specify the program educational objectives (PEOs) and prepare a mapping between the PEO and their specified outcomes.*'

A further 125 points are available for Curriculum, which is subdivided into 'Contents of basic sciences, HSS, professional core and electives, and breadth' [40 points], 'Emphasis on laboratory and project work' [30 points], 'Curriculum updates and PEO reviews' [30 points] and 'Additional contents to bridge curriculum gaps'[25 points].

No further elaboration is given on for example what the professional core and electives might entail. The rest of the points are allocated for items such as available resources and facilities.

5.12. Japan Accreditation Board for Engineering Education (JABEE)

Excerpts from the criteria for Accrediting Japanese Engineering Education Programs Leading to Bachelor's Degree (JABEE, 2009)

JABEE require eight general 'learning and educational objectives' criteria in addition to individual program criteria against specific named fields of engineering. These include:

Criterion 1: Establishment and Disclosure of Learning and Educational Objectives

(1) For the purpose of fostering self-reliant engineers, the program must establish specific learning and educational objectives that concretize the contents of knowledge and abilities

(a) An ability and intellectual foundation to consider issues from a global and multilateral viewpoint.

(b) Understanding of the effects and impact of engineering on society and nature, and of engineers' social responsibility (engineering ethics).

(e) Design abilities to organize comprehensive solutions to societal needs by exploiting various disciplines of science, engineering and information.

5.13. Taiwan - Institute of Engineering Education Taiwan (IEET)

Excerpts from the Institute of Engineering Education Taiwan Accreditation Council Accreditation Criteria 2010

The IEET have nine criteria for accreditation, including one on 'Program Outcomes and Assessment' (Criterion 3). This criterion has eight requirements for graduates of accredited programs, including:

3.1.7 knowledge of contemporary issues; an understanding of the impact of engineering solutions in environmental, societal, and global contexts; and the ability to cultivate habits of life-long learning

3.1.8 understanding of professional ethics and social responsibility.

5.14. Hong Kong - The Hong Kong Institution of Engineers (HKIE)

Excerpts from the Professional Accreditation Handbook (Engineering Degrees) (HKIE, 2003)

HKIE require a number of criteria for accreditation, including duration, resources, entry levels, etc as well as one under Syllabus and Curriculum. These criterion incorporates three headings; Engineering Subjects, Mathematics and Complimentary Studies. There are five listed topic requirements under Engineering Subjects including;

- *Engineering Design and Synthesis - Its establishment as a separate topic can be used to demonstrate that it is a creative, iterative and often open-ended process and to also enable discussion of general design techniques and philosophy, as well as financial, quality, safety and environmental implications.*

Complementary Studies incorporates four headings, including:

1. Health, Safety and the Environment - The programme should demonstrate the importance of health, safety and environmental considerations to both workers and the general public.

2. The Professional Engineer - It is considered that students should be introduced to the role of the professional engineer in practice and their responsibilities towards the profession, colleagues, employers, clients and the public, particularly with reference to the impact of technology on society and with regard to ethical behaviour

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