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EXPLORING SUSTAINABILITY THEMES IN ENGINEERING ACCREDITATION AND CURRICULA

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1. Abstract

Purpose- This paper presents key findings from an inquiry into engineering accreditation and curricula renewal. The research attempted to ascertain conceptions of requisite sustainability themes among engineering academics and professionals. The paper also reflects on the potential role of professional engineering institutions in embedding sustainability through their programme accreditation guidelines, and wider implications in terms of rapid curricula renewal.

Design/methodology/approach- This research comprised an international engineering academic workshop held during the 2010 International Symposium on Engineering Education in Ireland, on ‘Accreditation and Sustainable Engineering’. This built on the findings of a literature review that was distributed prior to the workshop. Data collection included individual questionnaires administered during the workshop, and notes scribed by workshop participants.

Findings- The literature review highlighted a wide range of perspectives across and within engineering disciplines, regarding what sustainability/sustainable development themes should be incorporated into engineering curricula, and regarding language and terminology. This was also reflected in the workshop discussions. Notwithstanding this diversity, clusters of sustainability themes and priority considerations were distilled from the literature review and workshop. These related to resources, technology, values, ethics, inter- and intra-generational equity, transdisciplinarity, and systems and complex thinking. Themes related to environmental and economic knowledge and skills received less attention by workshop participants than represented in the literature.

Originality/value- This paper provides an appreciation of the diversity of opinion regarding priority sustainability themes for engineering curricula, among a group of self-selected engineering academics who have a common interest in education for sustainable development. It also provides some insights and caveats on how these themes might be rapidly integrated into engineering curricula.

Keywords- Sustainability, Sustainable Development, Engineering Education, Professional Engineering Institutions, Rapid Curriculum Renewal

Paper type- Research paper

1. Introduction

The issue of sustainability and its appropriate role in engineering education has been the focus of growing awareness among the engineering education community globally, particularly during the last decade. However, while education for sustainability (EfS) literature shows there have been calls for embedding sustainability/sustainable development (SD) content throughout engineering curricula since the 1990s, there has been little by way of strategic and systemic integration (Allen *et al.,* 2010), creating a situation where the integration of sustainability knowledge and skills is delayed (Desha *et al.*, 2009).

Looking more broadly at curriculum renewal literature, it is clear that accreditation plays a key role in driving and monitoring curriculum renewal in this highly regulated discipline, generally managed by professional engineering institutions (PEIs) (Heywood, 2005; Byrne and Fitzpatrick, 2009). Moreover, PEIs are clearly active in responding to and anticipating future societal needs (for instance, IChemE, 2007). Hence, given the global drivers for engineers to deliver sustainable solutions (UNESCO, 2010; Smith *et al.*, 2010; von Weisacker *et al*., 2009), it is assumed that PEIs will be considering the issue of appropriately embedding EfS over future accreditation reviews and guideline iterations. There are already signals that this is happening, with a number of PEIs already embedding sustainability language into codes of ethics and graduate competency statements (see an overview of these in Byrne *et al*., 2010). With this context in mind, the authors were keen to compare what PEIs and engineering educators consider to be important sustainability themes (or graduate attributes) for the curriculum. Specifically, how much commonality exists in expectations between this key stakeholder and the engineering schools delivering education for sustainability (EfS) within the engineering programs? This paper presents key findings from the inquiry into focus areas for education for sustainability, and how this information could be used to assist future accreditation processes. It also considers how these might inform future accreditation guidelines, and wider implications for rapid curriculum renewal in undergraduate programs.

2. Research Method

This research comprised a qualitative mixed-method research approach, situated in curriculum renewal theory and education for sustainability theory. The method comprised an international engineering academic workshop and a short questionnaire at the conclusion of the workshop, which explored questions arising from a review of curriculum renewal and education for sustainability literature. Data collection included individual questionnaires administered during the workshop, and notes scribed by workshop participants, as described in the following paragraphs.

2.1 Workshop

The research method took advantage of the presence of academia, professional engineering institutions and industry at an international conference, which hosted disciplinary and interdisciplinary discussions about emerging themes. The workshop and questionnaire were completed on the final day of the 3rd International Symposium for Engineering Education (ISEE2010) at University College Cork (UCC), Ireland (Byrne, 2010). The theme of the symposium was '*Educating Engineers for Changing World – leading transformation from an unsustainable global society*' and the theme of the delegate workshop was 'Accreditation and sustainable engineering'. The workshop was facilitated by one of the research team, Cheryl Desha, education director of the Natural Edge Project (TNEP), using an adapted collective social learning method (Brown, 2008), with data subsequently recorded and analysed by team members in Ireland and Australia.

The aims of the 1.5 hour workshop were two-fold:

1. To provide an opportunity for members of PEIs, educational institutions and industry from Ireland and overseas to discuss emerging accreditation themes internationally, particularly in relation to engineering education for sustainable development (EESD).
2. To demonstrate an example process that could be used by any PEI or institution to discuss their own focus on sustainability/sustainable development.

Forty-three workshop participants were drawn from symposium delegates as a self-selected group and were provided with an advance copy of a specially compiled paper authored by the research team, which reviewed international progress on engineering education for sustainable development, including relevant programme accreditation requirements (Byrne *et al.*, 2010). Participants were invited to select a group to work in (approximately equal numbers in each) from 7 disciplinary options comprising: Chemical/ Environmental (2 groups); Civil/Structural; Mechanical/Materials; Electrical; Information, Telecommunications, and Electronics; and Other (which comprised an agricultural engineer, a social scientist and other practicing engineers). In groups, the participants considered the following visioning 'blue sky' question:

> *'What Sustainability/Sustainable Development themes should be incorporated into engineering curricula for the second decade of the 21st Century and beyond?'*

Outputs from these groups are presented in Appendix A, tables A1-A7. The disciplinary groups were then asked to highlight the themes which they felt represented *'priority areas that could be focused on in the next 5 years'* for their respective disciplines (these are highlighted **in bold** through tables A1-A7). Participants were also asked to identify areas they considered were well covered by current guidelines of Professional Engineering Institutions. This was followed by a session where each group reported their discussions to the wider group, while other groups considered any amendments to their own list, identifying potential opportunities for multi-discipline co-operation on specific attributes.

In order to allow some comparisons to be made, the data was qualitatively analysed using a clustering method which is based on other published studies where students' understanding of SD concepts have been considered (Segalàs et al., 2008, 2010; Shallcross, 2010). The categories are identical to Shallcross's categorisation with the exception that 'values and ethics' are clustered with 'intra-generational and inter-generational equity' instead of 'social impacts' and 'environmental pollution' is listed instead of 'environmental'. The latter change is made to better reflect the themes outlined in this category and because the themes under the category of 'resources' as well as 'environmental pollution' could equally be classified under the general theme of 'environmental' (sustainability) as classified by Lourdel et al (2007). In addition, one additional category is used; that of 'trans-disciplinary, systems and complex thinking'. Thus the list of nine categories is as follows: 1. Environmental pollution (V); 2. Resources (R); 3. Social Impact (S); 4. Values/Ethics/Inter and Intra-generational equity (I); 5. Technology (T); 6. Economic (C); 7. Education (D); 8. Actors and Stakeholders (A); 9. Trans-disciplinary, Systems and Complex Thinking (X). The ordering of the groups is arbitrary and is merely chosen to align with the ordering used by previous studies (e.g. Shallcross, 2010).

Of course the categories listed here are not mutually exclusive and there is potential for overlap. Moreover, different themes may have different meanings and interpretations among different people. For example, while the theme of 'wind power' is categorised under 'resources' it could also be viewed as being more appropriately designated under 'technology' while it also can have 'environmental', 'economic' and 'social impact' considerations. Thus the categorisation awarded here is in no way claimed to be definitive, but merely an interpretation by the authors providing an indicative overview of respective clusters around selected categories which can be attributed to sustainability/sustainable development.

2.2 Participant Questionnaire

A short survey was administered on an individual basis to cross-check individual perceptions related to EESD with the data generated during group discussions. Twenty participants completed the questionnaire, with a number of participants needing to move quickly to the next symposium session.

The questionnaire asked respondents to indicate how strongly they agreed or otherwise with a series of five closed statements. Two open-ended questions were also included, related to participant opinions on core sustainability related competencies.

3. Outcomes and analysis - Workshop

Just over half of the workshop delegates came from Ireland (both the Republic and Northern Ireland) with participants also from Australia, England, Finland, Italy, Portugal, Scotland, Sudan, Sweden and the USA. The Symposium also included representatives from a number of PEIs for a Professional Institutions Forum (see ISEE2010, 2010) as part of the symposium on the theme of considering the appropriate relationships between sustainability/sustainable development and engineering education for the 21st Century. PEIs represented included Engineers Australia, the Institution of Chemical Engineers (IChemE), Engineers Ireland and the Institution of Mechanical Engineers (IMechE).

3.1 Sustainability related curricula themes

Each of the blue-sky sustainability/sustainable development themes indicated by the groups was attributed to one of the nine listed categories as summarised in Table 1 (cluster labels ordered as presented in Shallcross paper (2010)). The raw data is included in Appendix A.

TABLE 1. AGGREGATED CURRICULA THEMES BY DISCIPLINARY GROUPS

Cluster Labels/Workshop Groups	Chem/ Env 1	Chem/ Env 2	Civil/ Structures	Mech/ Materials	Electrical	IT/Tele/ Electronics	Others	All (Prioritised)
Environmental Pollution (V)	2	-	1	4	-	-	-	7 **(2)**
Resources (R)	6	1	4	9	4	3	1	28 **(14)**
Social Impact (S)	3	1			1	1	1	7 **(1)**
Values/Ethics/Inter & Intra-generational Equity (I)	5	2	4	1	1	6	5	24 **(5)**
Technology (T)	9	-	2	3	1	2	2	19 **(4)**
Economic (C)	1	1	1	-	-	1	1	5 **(0)**
Education (D)	3	-	1	1	1	1	1	8 **(1)**

Actors and Stakeholders (A)	1	2	1	-	-	3	-	7 **(2)**
Trans-disciplinary, Systems & Complex Thinking (X)	2	5	3	1	1	1	1	14 **(6)**
Totals	32	12	17	19	9	18	12	119 **(35)**

Because of the small and self-selecting nature of the participants to both the symposium and workshop (it might be assumed that there was a general favourable bias towards and interest in EESD), the results of this workshop could not be construed as representative of either academics or PEI executives across the respective disciplines. Nevertheless a number of trends are apparent from the collated data (Table 1).

Three categories stand out in terms of themes which participants considered should be incorporated into engineering curricula. These are in order of popularity; 'resources', 'values/ethics/intergenerational and intragenerational equity' and 'technology'. Of these, 'resources' themes were identified as being easily the most common priority areas that should be focused on over the next five years. Renewable fuel sources featured strongly including wind, solar, biofuels and wave/tidal. Life cycle analysis/management also featured as did the issue of water. Ethics and responsibility featured among a number of groups as a priority theme as did integrated design/systems thinking as well as thermodynamics.

One indicator of how non-representative of their respective disciplines the groups could be was borne out by the results provided by the two chemical and environmental engineering groups (See Appendix 1 (Tables A1 & A2)). Their contrasting responses are perhaps a good indicator of the disparate views held by engineering educators and practitioners towards the issue at hand. While the first group focussed on resources and technology themes, which comprised almost half the areas identified, the second group scarcely mentioned these and instead placed a major emphasis on transdisciplinary, systems and complex thinking themes as well as actors and stakeholders and values and ethics. These outcomes also potentially highlight the affects of 'groupthink'; a situation where the group collectively coalesces around particular aspects of the issue under consideration.

Notwithstanding this observation, clear trends are also evident among the disciplines. While there is some overlap across groups, there are nevertheless a wide and disparate number of themes identified by the respective groups. 'Resources' were highlighted as key themes by both the mechanical and materials engineers and by the electrical engineering groups, both placed little emphasis on 'values, ethics and intergenerational/intragenerational equity' themes. By contrast the IT/telecommunication and electronics engineers and the group of 'others' placed significant emphasis on themes around values, ethics and social responsibility and less so on 'resources' and 'technology'.

Overall, the broad range of themes identified is perhaps as much an indicator of the breadth covered by the sustainability/sustainable development landscape as it is a demonstration of the diversity of opinion among interested engineering educators, practitioners and PEI personnel.

3.2 Accreditation coverage of sustainability themes

Participants of the workshop were asked to identify areas relating to sustainability/ sustainable development which they considered were well covered by current curriculum accreditation guidelines of Professional Engineering Institutions (PEIs) and to identify to what extent they felt these were covered by engineering curriculum. They had been issued with a review paper concerning the current position across a range of PEIs globally (Byrne *et al.,* 2010) in advance of the workshop to provide some context.

Many groups could not or did not indicate to what extent they felt stated areas were covered. In some cases participants noted that they were not sure what the accreditation guidelines required, because they varied between PEIs, or due to time constraints. Where groups did identify areas, there was little consensus. This included for example a perception of high coverage of 'design and sustainability integration (process and product)' (chem/env group 1) and of 'eco/ethics' (others). Moderate coverage was attributed to areas in 'energy and sustainable energy' (chem/env group 1) and 'legal–policy–regulations' (others). Low coverage was attributed to 'engineers as agents of social change' (chem/env group 1), 'systematic decision making' (civil/structural), 'design – including resource management (civil/structural) and 'recognition of interdisciplinary issues including listening' (civil/structural).

Other areas mentioned included: 'creative/ flexible incentives to embed sustainability into teaching and learning', 'student projects, staff rewards, leadership/ college commitment', 'professional development leading to competencies (evaluation effectiveness?)', 'making implicit more explicit', 'awareness of sustainable development in earlier years', 'global/local awareness – motivation', 'materials/life cycle management/ product design', 'thermodynamics', 'alternative energy', 'problem solving skills/decision making processes', 'renewable energy – power', 'recyclability/reusability – extending life cycle (resource management)', 'exploitation – knowing limits – smart meter technology, smart systems technologies', 'exposure & awareness', 'knowledge' [of sustainability/SD], 'commitment to practice, and influence, agents of change', 'validation tools – whole system solutions', 'new thinking on chemistry (molecular transformation)'.

The final part of the workshop consisted of a session where each group reported their discussions to the wider group, enabling other groups to consider any amendments to their own list or to consider potential opportunities for multi-discipline co-operation on specific areas. The role of PEIs and their accreditation boards were discussed including the role of the latter in disseminating good practice, sharing examples and providing for staff to come into contact with champions. Some participants cautioned at overemphasizing the role that PEIs might play in curriculum change; one argued that PEIs must strike a balance between degree of enforcement and academic freedom while another suggested that an emphasis on sustainability by PEIs could actually lead to contempt and should thus be removed.

A wide range of additional suggestions and observations were also proposed by groups. A number of groups alluded to the idea that engineers act as agents of social change. Other groups pointed out the need for communication and sharing experiences at national, trans-national and disciplinary and trans-disciplinary levels. One group mentioned the possibility of student engagement in curriculum design while other comments were around the decision-making process, promoting ethos and empowerment of leadership, measuring the unmeasurable and resource driven design.

4. Outcomes and analysis – Participant questionnaire

Aggregated responses to the questionnaire respective statements are related in Table 2. It is hardly surprising that none of the delegates agreed that sustainability knowledge and skills are *thoroughly embedded* within the engineering curriculum within their university. On whether they felt that PEI accreditation criteria *caused* their academic unit or institution to formalise inclusion of sustainability knowledge and skills into the curriculum, most disagreed though a minority suggested that this was the case. This probably reflects the complex nature of the endeavour (of incorporating EESD into curricula), with multiple actors potentially influencing curriculum evolution. While a majority agreed that they felt they understood their ability to apply sustainability criteria within their respective discipline's accreditation requirements to their own programme, a significant number were neutral on this while some disagreed.

These responses, and indeed responses to all the statements, should be viewed taking into consideration that that conceptions of sustainability/sustainable development are normative and can therefore differ considerably among individual actors and institutions, for example, ranging from very weak to very strong versions of sustainability and with corresponding differing emphases on the significance of different themes and aspects. Indeed this variation is borne out by both the group and individual responses. Finally, there was some agreement with the statements concerning whether participants would like assistance from PEIs on understanding what sustainability knowledge and skills should be addressed for accreditation purposes and on whether there are important sustainability competencies currently missing from their discipline's accreditation criteria, though a large minority neither agreed nor disagreed with both these statements.

TABLE 2. SUMMARY OF RESPONSES TO INDIVIDUAL WORKSHOP SURVEY

Survey Question	Strongly Disagreed	Disagreed	Neutral	Agreed	Strongly Agreed
Sustainability knowledge and skills are thoroughly embedded within the engineering curriculum in my university	5	10	5	-	-
Accreditation criteria caused my school/department/institution to formalise inclusion of sustainability knowledge and skills into the curriculum	4	7	4	4	-
I understand how to apply sustainability criteria within my discipline's accreditation requirements to my program/s	1	2	5	7	3
I would like assistance from my Professional Engineering Institution (PEI) to understand what sustainability knowledge and skills should be addressed for accreditation purposes	2	-	8	7	1
I think there are important sustainability competencies currently missing from my discipline's accreditation criteria	1	3	9	4	2

A more detailed understanding of delegates attitudes towards required core sustainability competencies and the associated role of PEIs was obtained from a supplementary question on the issue: "*When accreditation bodies are reviewing their core competency statements for sustainability content, the most important thing that they should consider is*".

Answers to this question were grouped into two clear clusters among respondents. About half of the responses suggested that *embedding* sustainability throughout the curriculum should be a key aim. The rest expressed some concern that PEIs needed to be careful not to be overly prescriptive or formulaic in defining requirements and felt that it was generally up to universities to lead rather than follow since, as one respondent put it, they are *'independent and capable of creative approaches to sustainability'*.

A second supplementary question asked participants the following: *"If I had to choose three sustainability related competencies that are most important for my discipline, they would be"*.

Responses to this question were characterised by a good deal of variety as with the group exercise outlined above. Indeed, in order to consider them collectively, each of the competencies were assigned to one of the nine previously identified themes (Table 3). Again, many of the competencies could be assigned to quite a number of themes, and thus the designations here may not entirely align with their intended meaning by the participants. The outcome however provides an indicative and general overview of the themes identified.

As with the group exercise, there was a good representation across the nine themes, with 'resources' related competencies again coming out top, though there was less an emphasis on both 'technology' and 'values/ethics/inter & intragenerational equity' in favour of 'transdisciplinary, systems & complex thinking'. Of the latter theme, the issues of risk/uncertainty and of adopting a (complex/) systems approach featured strongly. Overall, the broad range of competencies identified by the twenty participants is probably representative of the wide range of views that one might expect on this issue, even among interested academics, professionals and 'experts'. It also shows the wide range of issues that can be usefully accommodated under the umbrella of sustainability.

TABLE 3. RESPONSES TO INDIVIDUAL WORKSHOP SURVEY QUESTION 2

'If I had to choose three sustainability related competencies that are most important for my discipline, they would be:'	
Resources (11) End of life consideration/holistic design Recognition of renewable/non-renewable resources Ecodesign strategies, how to transition from product to service Life cycle energy analysis capability Broad appreciation of the energy challenge Product life cycle assessment In depth understanding of material issues Understanding resource limitations Biomaterials Resources security Re-useability, recycling	**Transdisciplinary, Systems & Complex Thinking (8)** Understanding of complexity and complex systems Whole systems approach Whole system design Risk assessment and simulation Critical analysis Thermodynamics Ability to estimate Ability to assess impact of current and proposed technologies
Environmental Pollution (4) Environmental impact of materials/processes Environmental impacts Effects of acoustics on the environment Disposal of waste materials/alleviation of fumes	**Social Impact (4)** Societal impact of engineering decision making Need for communicating contribution from engineers to society Awareness of environmental and social impacts of electronics/ICT Process impact evaluation
Actors and Stakeholders (4) Communication skills Leadership or champions Communication	**Economic (3)** Sustainability management systems Green logistics Competitiveness through sustainability

Team work	
Values/Ethics/Inter & Intragenerational equity (3) A sense of micro and macro ethics regarding electronics/ICT Greediness reduction Ethical imperatives	**Education (3)** Deep understanding of concepts and tools Acknowledgement of coupling social/technical/economic aspects General understanding of sustainability
Technology (3) Inventive problem solving/biomimicry In depth understanding of design issues Lean and green manufacturing	

5. Discussion

5.1 Comparison with other studies

The current work makes for interesting comparison with other studies on students, researchers and engineering practitioners. For example, Segalàs *et al.* (2008, 2010) looked at the perceptions of engineering students across a number of European institutions on programmes with a strong emphasis on sustainable development and found that they *'basically understand sustainability as a technological and environmental issue and they rarely relate it to social or institutional aspects'.* They also found that students' perceptions change slightly (with greater emphasis on institutional and social) but not substantially before and after taking relevant courses. Based on students' perceptions of sustainability/sustainable development as gleaned through concept maps, the three main themes both before and after taking SD related courses were 'technology', 'environmental' and 'resources' respectively. A similar concept map study by Shallcross (2010) on 732 first year engineering students at the University of Melbourne also found 'technological' themes most prevalent, followed by 'social impacts and values' and environmental' themes respectively. By contrast Segalàs *et al.* (2010) also surveyed a group of 25 EESD 'experts' who related contrasting conceptions of important sustainability themes; relating sustainability *'mainly to social and institutional aspects and less to technological and environmental issues.'*

Lourdel *et al*., (2007) carried out another concept map study on students of a French graduate engineering school having taken SD training and compared their perceptions with those of their professors, who were also researchers in the department of Science, Information and Technology for the Environment (SITE). The small number of students surveyed (ten) considered 'multidisciplinary' themes as rating highest while 'economic scientific' themes were least prominent. Unsurprisingly given the limited numbers, these results carried *'relatively high'* standard deviations. Providing results displaying similarity to the current study, the themes chosen by the researchers *'were totally dissimilar'*, which the authors suggested correlated *'to the diversity of research themes within this department (SD, best available technologies, modelling of air pollution, industrial risk).'* Consequently while 'multidisciplinary', 'economic scientific', 'environmental' and 'social, cultural' all scored highly, the associated standard deviations were also very high.

Dwyer and Byrne (2010) surveyed seventeen professional engineers with a range of international backgrounds (mainly chemical engineers, but also environmental, industrial, mechanical, etc.) who worked with a leading Australian multi-disciplinary consultancy specialised in engaging organisations in their responses to climate change and sustainability. Participants suggested that the most prevalent themes they employed in their current work were ‘regulations’, ‘environmental versus cost balance’, ‘life cycle analysis’ and ‘multidisciplinary work’ respectively. These themes were generally comparable with the extent to which the engineers were exposed to previously as part of their formative engineering education (with the exception of ‘multidisciplinary work’, which did not feature highly in their educational programmes). By contrast ‘qualitative aspects’, ‘input from non engineers’, ‘social/political and societal context’ and the ‘ethical framework’ did not figure highly at all and in fact, virtually all the engineers would choose to describe themselves as *‘agents of the client, bounded by their needs and requirements and the law’* rather than ‘*ethical professionals with a responsibility to society at large as well as the client’.*

5.2 Implications for rapid curriculum renewal

Previous work by Desha, Hargroves and colleagues has highlighted the need for rapid curriculum renewal of professional engineering programmes globally to address deficiencies in key competencies in contemporary programmes in light of emerging symptoms of the current unsustainable societal construct such as climate change (Desha *et al.*, 2009; Desha and Hargroves, 2011). Critically, this will require buy in from both academics involved in designing and delivering programmes and accrediting PEIs. Though evolving in line with broader societal and political expectations, the requirement for EESD themes and concepts (as outlined above) in accreditation guidelines across global PEIs is highly variable at present (Byrne *et al.*, 2010) ranging from reasonable to non-existent. Similarly the current study, in agreement with other cited studies, shows at best a wide range of opinions and understandings and a general disparity among what the key EESD themes for engineering curricula should be among academics and practitioners.

While homogeneity in this emerging field is neither possible nor desirable (Segalàs *et al.,* 2009), it *is* both possible and desirable the authors would contend, to have each of the sustainability themes *embedded* throughout professional engineering programmes to be fit for purpose for the second decade of the twenty first century and beyond. This will however require a substantial curriculum shift to result in engineering graduates who will see themselves more as *‘ethical professionals with a responsibility to society’* than merely paid hands acting as more or less uncritical *‘agents of the client’*. Such a programme will by its nature explicitly examine the values, ethics and social responsibility of the engineer in a broader context than heretofore and develop skills for multi- and trans-disciplinary endeavour, including post normal scientific approaches to wicked problems and involving actor and stakeholder engagement.

Rather than a single ‘big bang’ top-down approach to accomplish these developments, it is far more likely, in the nature of complex adaptive systems, that rapid change will ultimately come about through non-linear, organic engagement among networks of interested and committed academics and stakeholders, which will concurrently find the developing broader (societal, institutional and PEI/accreditation) context an increasingly fertile medium for growth until such point that the sudden onset of a tipping point will see rapid realisation of this shift. This can (and must) of course be aided by other norm changing inputs such as top down measures including management buy-in across universities (see e.g. Desha and Hargroves, 2007), within programmes and through PEI accreditation guidelines (see Byrne and Fitzpatrick, 2009). In short, bottom-up, top-down and middle-out approaches are needed to elicit the necessary change (Mulder, 2006; Mulder *et al.*, 2010). The manifestation of these combined drivers will in turn be elements such as increased awareness and outreach, content and curriculum development, greater curriculum auditing for sustainability/sustainable development, and campus and trans-disciplinary integration (Hargroves and Smith, 2005; Desha and Hargroves, 2011).

The two largest barriers to engineering education curriculum renewal identified in a recent Australian survey were *'the potential for course content overload'* and *'having insufficient time to prepare new materials'* respectively (Desha and Hargroves, 2010). In fact, each of these factors was identified by a majority of lecturers surveyed. However, the first reservation can be allayed if the sustainability themes are to be *embedded* across the curriculum and thus considered as the very *context* of engineering education (Byrne, 2009; Byrne and Fitzpatrick, 2009). Indeed apart from aligning with the trans-disciplinary ethos around sustainability, such an integrative approach is something which is a requirement for a meaningful contribution to SD (Holmberg *et al.*, 2006; Mulder *et al.,* 2010). It also finds favour among a substantial number of students, as evidenced by a recent first year higher education survey across the UK (Agombar and Bone, 2010). The second barrier is a genuine hurdle for all but the committed, and thus it is most likely to fall to dedicated academic researchers, lecturers and early adapters to prepare and develop an appropriate epistemological basis and related academic research, materials and monographs to help prime mass curriculum renewal. In accordance with the range of sustainability themes identified in this paper and elsewhere, such pioneers will be open to multi and trans-disciplinary approaches which will transcend narrow disciplinary bounds (Thomas, 2004), will ascribe to the values (largely intrinsic) that underpin a sustainability ethos (see WWF, 2010) and will recognise the social, ethical and normative dimensions to sustainability in addition to the environmental and technical.

5.3 Role of PEIs through the accreditation process

There are some significant barriers to PEIs being proactive agents of curriculum renewal towards EESD. An English study into sustainable development across higher education there (HEFCE, 2008) found similar barriers to implementation as mentioned above, but also the added barrier of professional bodies themselves, whose *'perceived conservatism'* in fact *'acted as a barrier'*. Engineering it was noted however, *'might be one exception'* to this, and the Royal Academy of Engineering (RAE) in particular was singled out for its integrative approach. In this context the report noted the *'the absolute importance of involving the professional bodies in future SD policy and practice.'*

Indeed the RAE have recognised the potential of the accreditation process as a key driver for evolution and renewal. It has argued 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'* (RAE, 2007). Furthermore, this British institution has promoted sustainable development concepts through a published set of twelve 'Guiding Principles' for engineering for sustainable development (RAE, 2005) in a document which also provides examples and applications for curriculum implementation, and has 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 importance of accreditation as a driver for curriculum renewal towards EESD is also reflected in countries such as Australia and the United States of America. In Australia a national review of engineering education (King, 2008) identified the need for education for sustainability. Furthermore, subsequent reviews of the Stage 1 (graduate) and Stage 2 (professional) competency standards, which underpin program accreditation, identified a significant need for sustainability to be embedded throughout the graduate attributes. In America, the Accreditation Board for Engineering and Technology (ABET) requires engineers to be able to design a system, component or process to meed desired needs within realistic constrains including sustainability considerations (Abraham, 2006). This is supported by other documents such as the American Society for Civil Engineers' code of ethics statements, which embed sustainability into the tenets of practice.

Hence, despite a degree of scepticism in the literature and among some workshop delegates regarding the importance of the role of PEIs in helping embed sustainability themes and concepts across curricula, the literature points to PEI accreditation guidelines with their ongoing evolution, playing an important iterative feedback role in the renewal process towards EESD. This is evidenced by the rapidly growing set of code of ethics documents, sustainability charters and supporting guidance documentation being produced by PEIs internationally (Byrne *et al.,* 2010), and the recent focus of the International Engineering Alliance on sustainability during their review of graduate attributes and professional competencies. It is also evidenced by an observed correlation between levels of EESD curriculum renewal across certain regions and countries globally (EESD Observatory, 2008; Wood, 2010) and correspondingly rigorous treatment of sustainability concepts within accreditation documentation of corresponding regional PEIs (Byrne et al., 2010).

Within this context, it is clear that the role of PEIs has been an important one over the last decade, developing criteria and guidance for embedding sustainability into the curriculum. Moving forward, the role for PEIs is one of ensuring that the intentions of these criteria are embedded within the programs that are reviewed and accredited herein. This will require addressing a range of barriers noted in this paper, to overcome challenges associated with understanding the implications of the competency criteria, code of ethics statements and other such documents, being able to target or prioritise sustainability related competencies during accreditation reviews, and a potential lack of sustainability related knowledge and skills among accreditation panel members who are often volunteers with their own time and resourcing constraints.

6. Conclusions

This paper has inquired into perspectives on engineering curricula sustainability themes and accreditation implications, drawing on documented experiences of colleagues internationally, and analysing the results of an international workshop on 'Accreditation and Sustainable Engineering'.

In the workshop, engineering academics and practitioners identified a wide range of sustainability competencies that they consider as requisite for fit for purpose curricula of the second decade of the twenty first century and beyond. When these are categorised under nine thematic headings, the most important sustainability related competencies as identified by participants were those under 'resources', 'technology', 'values/ethics/inter & intragenerational equity' and 'transdisciplinary, systems & complex thinking'. In contrast 'environmental pollution' and 'economic' concepts attracted less emphasis from participants, perhaps indicating a feeling that these are already relatively well catered for through engineering curricula. The broad scope of competencies identified not only emphasizes the diverse nature of sustainability concepts, traversing traditional disciplinary bounds, but also demonstrates the normative and potentially contested conceptions of sustainability/sustainable development, even among those with an interest in promoting and embedding it across programmes.

While educators as coalface advocates will play a key role in the renewal of engineering curricula, they being the ones who ultimately develop and deliver material, this is a complex process whereby top-down institutional acceptance and promotion and the advocacy of PEIs particularly through programme accreditation guidelines will also play a part, particularly if rapid curriculum renewal is to be achieved. A requirement to embed sustainability/ sustainable development concepts right across curricula so that they act as *context* has been identified as a potentially important role for PEIs through their evolving accreditation guidelines.

Whole programme integration of sustainability/sustainable development as a context and ethos throughout the curriculum can help resolve the potential problem of sustainability being seen as yet another content heavy imposition on already overloaded curricula. However, top-down institutional advocacy from PEIs through the accreditation process however needs to be careful not to step into the realms of prescriptiveness and conformity; such an approach is more likely to alienate a proportion of the academics and lecturers responsible for programme delivery and could result in an opposite effect to that intended. Instead, broad guidance, context and support should be provided from PEIs and from academic institutions which can fuse with existing non-linear and organic bottom-up and middle-out creativity, initiative and innovation of interested and committed academics and stakeholders to provide the context and conditions for a substantial shift in curriculum, and concurrent rapid curriculum renewal.

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Appendix 1. Raw data from the ISEE participant workshop, 2010

In the tables, priority areas identified by the groups are presented in bold.

TABLE A1: CHEMICAL/ ENVIRONMENTAL ENGINEERING (GROUP 1 OF 2)

Energy and its sustainability (R)	**Risk Assessment and simulation (X)**
Water (R)	**Life Cycle Analysis (R)**
Manage extractive process SAFELY (R)	**Environmental Impact Assessment (V)**
SAFETY (X)	**Environmental Management Systems (V)**
Community lifestyle (S)	**Whole system design (T)**
Convenience (A)	**Responsibility (I)**
Backcasting (I)	
Communication (S)	Food (R)
Intensive reactors (T)	Rapid construction of infrastructure (T)
Carbon capture (T)	Mobility (S)
Adaptation (T)	Appropriate technology (T)
Resource scarcity (R)	Information technology – I. Flow 2050+ (T)
Sustainable economics (C)	What do you mean by sustainability/ SD? (I)
Sustainable education (D)	Education – kinder to university (D)
Exhaust fossil resources (R)	War (I)
Clean technology (T) CPD + sustainability (D)	Definition of sustainable concepts and application through the curriculum (I)

TABLE A2: CHEMICAL/ ENVIRONMENTAL ENGINEERING (GROUP 2 OF 2)

Integrated design (X)	**Thermodynamics** - > can/ can't do – examples/ anecdotes/ case studies (X)
Ethics (I)	**'Post-normal' science** -> honest-broker practice (A)
Competencies: - Complexity/systems thinking/uncertainty (X) - (moral) leadership (I) - Communication (S) - Creativity (X) - Team-work (A)	Sustainability assessment/ tools/ metrics – environmental, social, economic, technical (C) Challenges: Local/Global (X) Life cycles – LCA -> System boundaries for mass/ energy balance (R)

TABLE A3: CIVIL/ STRUCTURAL ENGINEERING

(no bolded items indicated by group)

Sequestration (T)	Intergenerational issues (I)
Resources & limitations (qualitative and quantitative) (R)	Communication – listening; public; specialists (A)
Energy accounting (V)	Professional development (D)
Carbon/s accounting/ validation (X)	Economics issues (C)
Interdisciplinary (relevant) (X)	Ethics – care – justice and relationships with the wider society; population control/ projections (I)
Complexity/uncertainty – risk (X)	Policy and regulation (I)
Spatial international issues (I)	Water accounting/ valuation (R)
Embedding/ normalising ESSD – sustainable engineering = good engineering (I)	Food (R)
Material selection and specification (T)	

TABLE A4: MECHANICAL/ MATERIALS

Materials (T)	**Fuel cells and hydrogen (R)**
Thermodynamics (X) **Life cycle management** - Scarcity of resources; process/ manufacturing; material extraction/ refining (R) **Product design (T)** **Biofuels (R)**	**Wind power (R)** **Alternative energy –** combined heat and power plant (R) **Solar power (R)** **Wave/tidal energy (R)**
'Promoting engineering related education for sustainable society' (D) Peak oil (R) Atmospheric carbon dioxide (V) Carbon dioxide growth rate (V) Quality of life – ethical and social awareness and responsibility - environmental, ecological (I)	Sequestration (T) Water scarcity (R) Climate change (V) Sea levels (V)

TABLE A5: ELECTRICAL ENGINEERING

Problem solving/ self learning/ reflection (D)	**Automation – exploitation (T)**
Renewables (R)	**Recycling/ life cycles (R)**
People/ students (S) Awareness of global/env/economic, etc – interdisciplinarity, influences (X) Energy efficiency awareness (R)	Production of electricity – fuel sources (R) Limitations/ stewardship (I)

TABLE A6: INFORMATION TECHNOLOGY, TELECOMMUNICATIONS & ELECTRONICS

No bolded item indicated by group
Problem solving through the filter of sustainability imperatives (A)
Promoting solutions with maximum longevity (I)
Patterns of sustainability: Consumer; Supply chains (resource limitations); Market; (C) Materials (resource limitations) (R); Skills set
Predictive sustainability: Climatic changes; Social trends; Mobility patterns; Policy (I)
Innovation – including continuous research (D)
Communication: Sharing experiences; Broadening the context; Policy issues (national & international); Promoting the ethos; Engendering and empowerment; Leadership (attributes of our graduate) (I)
Interdisciplinary areas (I): Decision making processes (A), abilities; Resource management practice (R); Life-cycles of equipment (R), extension, decision tools; Awareness of efficient solutions (T); Group working performance (A); Good practice in product design (T); Engineers as a agents of social change (S); Ethics (I); Systems thinking (X); Social responsibility (I)

TABLE A7: 'OTHER' ENGINEERING (MIXED TABLE)

Eco/Ethics (I)	**Legal – Policy – Regulations (I)**
Systems thinking (X)	
Raising awareness (D) Social (S) Eco-Design (T) Energy (R) Values/ Judgement (I)	Economics (C) Further change of mindset (I) Lean/ Green manufacturing (T) Equality (I)