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The evolving engineer; professional accreditation sustainability criteria and societal imperatives and norms

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ABSTRACT

Professional accreditation criteria around sustainability are an important consideration in the delivery of accredited (chemical) engineering programmes. This paper looks at the sustainability related criteria required by a number of professional bodies, while considering the evolution of such criteria over the past decades. It is seen that the scope and breadth of sustainability criteria has expanded among many accreditation bodies, including the Institution of Chemical Engineers, in line with institutional and professional imperatives. This has promoted the incorporation of a far broader range of sustainability related attributes than was previously envisaged. There are nevertheless large differences between the requirements of the various professional bodies considered, and in programmes across the world. The impact of societal imperatives and norms, including those of employers is reflected upon, as is the awareness and concerns of young people, who as graduates will be working through mid-century, directly engaging with sustainability related imperatives. IChemE accredited programmes are increasingly obliged to actively engage with contemporary sustainability related requirements more broadly, requiring increased integration of sustainability attributes across the curriculum, in terms of knowledge, skills and values. This evolution is important in remaining relevant as a profession, and in playing a key role in addressing societal challenges.

1. Introduction

Sustainable development and sustainability imperatives have been flagged by professional organizations since the early 1990s (Byrne et al., 2010; 2013). This decade precipitated the beginning of a potentially paradigmatic shift from envisioning sustainability as (yet another) *constraint* on engineering design and practice (e.g. ABET (2007), requiring that graduates of accredited programmes have "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") to one where sustainability is the very *context* of engineering practice. The 1997 Joint Conference on Engineering Education and Training for Sustainable Development in Paris, called on sustainability to be "integrated into engineering education, at all levels from foundation courses to ongoing projects and research" (JCEETSD, 1997; Byrne and Fitzpatrick, 2009). To this end, the conference exhorted professional engineering institutions to "adopt accreditation policies that require the integration of sustainability in engineering teaching". These developments saw increased impetus in the early part of the new century, supported by the likes of the Engineering Education for Sustainable Development (EESD) conference series from 2002, held at TU Delft. During that time, the criteria required by professional accreditation bodies increasingly required the development of sustainable development and sustainability related competences, largely building on the environmental engineering imperatives which had preceded these. The initial focus was thus mainly on environmental sustainability, including topics such as environmental and eco-design, as well as life cycle analysis and industrial ecology (Segalas et al., 2018). Over time, this has broadened to more explicitly incorporate social and societal dimensions (Fitzpatrick, 2017; Martin et al., 2019), and to multi-, inter- and transdisciplinary and integrative approaches (Byrne and Mullally, 2016; Tejedor et al., 2018; Segalas et al., 2018; Nesbit et al., 2021; Gutierrez-Bucheli et al., 2022). The need to embrace complexity and uncertainty too has increasingly been linked to understanding and addressing sustainability issues (Byrne and Mullally, 2014; Diwekar et al., 2021; Engineering X, 2021). In addition, there is the global dimension to engineering education (Bourne and Neal, 2008; Byrne, 2014), as well as the requirement for engineering (education) to explicitly highlight the normative, value(s) based and ethical dimensions of the profession (Clift, 2006; Conlon, 2008; Byrne,

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2012; Mulder et al., 2012; Martin, 2020; Homan, 2020), including cross cutting issues around technological evolution and implications for ethical and sustainability dimensions in technical education (Hume, 2022). The need for critical thinking has also been a feature of these calls (Mulder et al., 2012), all the more so in recent times with the emergence of social media and a propensity for scientific rigour and fact to be displaced in a paranoid post-truth world of misinformation (Fenner, 2021). More recently, aspects of diversity, inclusion and equity or equality have also been included in EESD/sustainability contexts (Rao et al., 2013; Jahan et al., 2021). Arising out of one the earlier EESD conferences, the 2004 Barcelona Declaration stands as a manifesto for sustainability infused engineering education, a charter which was both ahead of its time, and has stood the test of time, as it incorporated many of the aforementioned imperatives (Barcelona Declaration, 2004). This declaration was given a dusting down in 2021, from which emerged the Cork Amendment (Fenner and Morgan, 2021) which called for "new competencies and perspectives. to *urgently* respond to the diverse planetary risks through an understanding of six imperatives: values, context, uncertainty, change, limits and vision by:

- Actively engaging in **rebuttal** of counter-factual information, alternative realities and denial of existing global threats
- Developing an **anticipatory future vision** which embraces the need for restructuring of how humans live on the Earth
- Delivering radical **change** through the co-generation of solutions across disciplines and with diverse Stakeholders
- Seeking **resilient, flexible** and **adaptive** engineered systems and essential critical infrastructure capable of operating within **diverse uncertainties**
- Operating within resource and technological **limits** whilst seeking innovations that go beyond "doing no harm"
- **Challenging orthodoxy** and honestly assess the risks and impacts that may be associated with some technological /scientific advances.

1.1. Chemical engineering education sustainable developments

Within engineering education, chemical engineering, with its systems approach has always been to the forefront in seeking to integrate sustainable development and sustainability into the curriculum. As far back as 1998, Clift identified the transformational change required as a paradigm shift from the earlier Mark I (technocentric) and Mark II (sociocentric) engineering self-conceptions to that of the explicitly "ecocentric" engineer (Clift, 1998). Similar calls were made around chemical engineering education by Azapagic et al. (2005); Clift (2006); Byrne and Fitzpatrick (2009); Glassey and Haile (2012) and Von Blottnitz et al. (2015).

The Melbourne Communiqué was signed in 2001 by twenty global chemical engineering institutions at the 6th World Congress, where the profession sought to recognise both the challenges that presented in the century ahead and the need to meet these complex challenges with inter- and transdisciplinary approaches: "We acknowledge both our professional responsibilities and the need to work with others as we strive to meet the challenges facing the world in the Twenty-First Century".

Clift (2006) reiterated the need to see beyond disciplinary bounds in this pursuit (not without difficulty for educators), while highlighting the leadership role chemical engineers can and must play: "Although the field is trans-disciplinary, the engineering contribution is essential and chemical engineering in particular must be central."

1.2. Professional accreditation bodies and required sustainability competences

As various academics and programmes seek to embed sustainability and related competences into their programmes over the past decades, so too have the criteria for professional accreditation bodies been evolving. These are of course influenced by evolving societal and professional norms, including a heightening sense of crisis around an unsustainable societal construct as this manifests in worsening climate impacts, heightened (inter)national targets, continuing increased biodiversity loss, environmental degradation, food and energy crises, resource and limit implications, and even global pandemic.

1.3. Institution of Chemical Engineers (IChemE) sustainability initiatives and progress

Chemical engineering, certainly wherever it is professionally led by the IChemE, has sought to actively lead in the regard, coherent with Clift's above cited call. Among professional accreditation bodies globally, the IChemE has evolved to a significant extent over the past decade in how it seeks the integration of a sustainable development/sustainability ethos across its accredited programmes through its accreditation criteria. This can be seen by a comparison of such matters in its current accreditation criteria (IChemE, 2021) (see below), compared with more modest requirements a decade ago, as outlined in a 2010 international review (Byrne et al., 2010).

This development has been in concert with the institution's own policy development, which in turn cohere with evolving societal imperatives in this space. Indeed, the institution claims itself to have been "the first UK professional engineering institution to seriously engage with sustainable development when in 1997 it published a report to commemorate the 75th anniversary entitled "Future Life" and sub-titled "Engineering Solutions for the Next Generation …Also, as part of the 75th anniversary activities the Institution published the London Communiqué enshrining its commitment to sustainable development in the education and training of its members" (IChemE, 2022). The London Communiqué included a sustainable development pledge to "work to make the world a better place for future generations." (Batterham, 2003). Follow on initiatives from the institution include the foundation of its Sustainability Special Interest Group in 2004, which has supported programme wide developments through competitions and prizes such as the Sustainability Teaching Award and the Macnab-Lacey Student Design Project Prize. IChemE's, 2007 Roadmap for 21st Century Chemical Engineering (IChemE, 2007) represented a manifesto on sustainability for the institution and its members, and it was followed up with "Chemical Engineering Matters" (IChemE, 2012; 2016), which sought to incorporate a number of broader aspects. More recent initiatives have included the "IChemE position on Climate Change" policy (IChemE, 2020) and the development of an online Sustainability Hub in 2021, a CPD training hub aiming to "inspire and support chemical engineers to make a positive impact on global sustainability as defined by the UN Sustainable Development Goals" (IChemE, 2021).

This paper considers the professional accreditation criteria of the IChemE alongside other engineering accreditation authorities globally, and will thus reflect on the changes that have occurred and are occurring in the conception of "sustainable development"; and "sustainability" as they relate to programme delivery and imperatives. It will also reflect on the role that the professional accreditation criteria have in helping realise the potential for chemical engineering to "be reinvigorated as it moves centre stage" (Byrne, 2009), through working with others (disciplines, professionals, citizens/publics, stakeholders) to meaningfully address broader societal sustainability related issues in the context of rapidly evolving societal imperatives and norms which require an unprecedented level of urgency and engagement.

2. Accreditation sustainability criteria

2.1. Sustainability attributes or competences

While "sustainable development" and latterly more commonly "sustainability" criteria were initially conceived of in a broadly environmental context (as referred to above), these have evolved to incorporate a broader set of "sustainability attributes" over the past two decades. The international Engineering Education for Sustainable Development (EESD) conference series, the latest and 10th which was hosted at University College Cork in 2021 (the 11th is a Colorado State University, June 2023), has increasingly hosted papers and discussions on the need for engineers/graduates to develop attributes to facilitate addressing sustainability issues in this broader sense. This includes the need to appreciate and handle system complexity and uncertainty; to embrace inter- and transdisciplinary approaches; integrative thinking; a globalised, interconnected, empathetic, and multi-cultural outlook and skillset; equity, diversity and inclusion; critical thinking (of anti-establishment and establishment norms); and critically, recognition of, and engagement with the normative, values based and ethical basis of engineering practice. These imperatives cohere with emerging contemporary research imperatives and on-the-ground experiences and engagement with engineering projects (e.g. McGookin et al., 2022; Revez et al., 2022).

These broader set of competences have been articulated by many (Wiek et al., 2011; Lozano et al., 2017), with Lozano et al. outlining a series of twelve sustainability competences, including for example, systems thinking; interdisciplinary work; anticipatory thinking; justice, responsibility, and ethics; critical thinking and analyses; empathy and change of perspective; and tolerance for ambiguity and uncertainty. Gutiérrez Ortiz et al. (2021) sought to articulate these as sustainability attributes, under the three concentric knowledge spheres of knowledge, skills and values, as follows:

- **Sustainability (core) knowledge** and **understanding**, including around the issues and challenges, as well as a deep appreciation of the importance of the social, ethical, ecological and economic dimensions of sustainability, and the interconnectedness of each.
- **Sustainability skills**: ability to develop appropriate greener technologies, processes and approaches.
- **Sustainability values**: e.g. concern for the environment, commitment to sustainable development, empathy, equality, diversity, commitment to social justice, flourishing communities, human well-being, etc.

Gutierrez-Bucheli et al. (2021) carried out a review of learning outcomes in sustainability in engineering education, and found nine "approaches", which they labelled as; integrative; triple bottom line; individual; cultural; cross-disciplinary; environmental; social; industrial; and technical. They placed these on Esbjörn-Hargens's (2010), integral education theory four quadrant model of experience (subjective), behavior (objective), culture (intersubjective), and systems (interobjective), describing "the basic perspectives an individual can take on reality". The subjective domains were found to be more lacking in engineering education on sustainability (based on literature outputs), in particular intersubjective (educational culture), which incorporates culture, political perspective, ethics and multiperspectivity, while subjective (educational experiences), which includes values and self-awareness is also more narrowly represented. By contrast, attitudes, behaviours, technical knowledge, communication and praxis were strongly represented under the objective (educational behaviour) quadrant, as were social, environmental, ecological and economic perspectives under interobjective (educational systems).

2.2. Professional body accreditation criteria sustainability word survey

2.2.1. Survey of accreditation criteria descriptors

As part of this study, the accreditation criteria documentation of a number of professional bodies was considered. Current guidelines were consulted in all cases, though in the case of the IChemE and Engineers Ireland, the previous iteration was also consulted, in order to get a sense of most recent change and progression. Both these institutions updated their accreditation criteria in 2021. The criteria thus considered were from:

1. ABET 2022–2023 Criteria for Accrediting Engineering Programs (ABET, 2022)
2. EUR-ACE Framework Standards and Guidelines (2021) (EUR-ACE, 2021)
3. Engineers Australia (Stage 1 Competency Standard for Professional Engineer) (Engineers Australia, 2019)
4. Engineers Ireland (2014 and 2021 iterations) (Engineers Ireland, 2014; 2021)
5. IChemE (2017 and 2021 iterations) (IChemE, 2017; 2021)

Following from the previous discussion about trends towards broader sustainability attributes, the respective accreditation criteria documents were considered for more than just "sustainability" or "sustainable development" references. To that end, nine categories were identified as follows:

a. Sustainability/Sustainable/Sustainable Development/United Nations Sustainable Development Goals (UN SDGs)
b. Equity/Equality, Diversity, Inclusion, EDI/DEI
c. Ethics/Ethical
d. Global
e. Environmental/Environment
f. Society/Societal/Social
g. Cultural/Multicultural
h. Multidisciplinarity/Interdisciplinary/Transdisciplinary
i. Complex Systems/Complex/ Complexity

The number of references to each are presented in Table 1. The number of times a word is mentioned does not of course confer absolute importance (including relative to other terms) as seen by a professional body in terms of requirement for integration into a programme. Nor does it indicate to what extent it is envisaged this may be done. The exercise however may help provide an indicative overview of the what respective accreditation bodies are seeking, including indicating trends. Moreover some, such as ABET and EUR-ACE take a concise high level approach; in the latter case, national bodies may interpret these more rigorously for example, while Engineers Australia present respective criteria succinctly in tabular form. On the other hand, Engineers Ireland and the IChemE provide more expansive and detailed documentation.

A number of further notes and caution should also be noted. Where words were mentioned in forewords and introductory pieces for example, these were counted, as they indicated a certain commitment by the institution to these issues. In each case, the professional/masters or chartered engineering qualification was considered, so mentions in the parts relating to associate, technician or baccalaureate programmes were not counted, to avoid double counting, although sections relating to general principles were included. Words out of context were not included, such as for example when "environment" is used as "learning environment". ABET include some proposed changes for next academic year (2023–4) and this text was included, as was the ABET piece relating to chemical engineering (though not other branches), though this added no additional words. All the other professional bodies relate to engineers more generally, excepting IChemE of course. To account for variation in documents, a normalisation of the figures is undertaken in Table 1, whereby the percentage mentions each heading takes up is indicated relative to the total for that professional body. This facilitates a global comparison and overview, including longitudinal trends emerging in the most recent accreditation criteria iterations for both Engineers Ireland and the IChemE.

2.2.2. Survey results and discussion

2.2.2.1. Sustainability/Sustainable/Sustainable Development/UN SDGs.

Table 1
Sustainability attribute mentions in accreditation criteria documentation.

	Sustainability/ Sustainable/ Sust. Dev./SDGs	EDI	Ethics	Global	Environment	Society/ Societal/ Social	Multi/ Cultural	Multi/Inter/Trans Disciplinarity	Complexity
ABET (2022–23)	1 (1/0/0/0) *5%*	**7** ***32%***	1 *5%*	**2** ***9%***	2 *9%*	3 (0/1/2) *14%*	**2** **(0/2)** ***9%***	1 (1/0/0) *5%*	3 *14%*
EUR-ACE (2021)	1 (0/1/0/0) *3%*	0 -	2 *7%*	2 *7%*	4 *13%*	**9** **(5/3/1)** ***30%***	0 -	2 (2/0/0) *7%*	**10** ***33%***
Engineers Australia	**12 (4/7/1/0)** ***26%***	2 *4%*	3 *6%*	1 *2%*	6 *13%*	7 (2/0/5) *15%*	4 (2/2) *9%*	2 (1/1/0) *4%*	10 *21%*
Engineers Ireland (2014)	4 (4/0/0/0) *9%*	0 -	6 *14%*	0 -	7 *16%*	**11** **(3/1/7)** ***25%***	3 (1/2) *7%*	**5** **(5/0/0)** ***12%***	8 *18%*
Engineers Ireland (2021)	**12 (6/3/1/2)** ***16%***	2 *3%*	10 *14%*	1 *1%*	**14** ***19%***	15 (5/2/7) *20%*	4 (1/3) *5%*	0 (4/0/0) *0%*	**16** ***21%***
IChemE (Aug 2017)	12 (9/0/3/0) *13%*	0 -	**28** ***30%***	0 -	**23** **25%**	9 (2/1/6) 10%	2 (2/0) 2%	2 (1/1/0) 2%	17 *18%*
IChemE (Oct 2021)	29 (22/5/1/1) *13%*	**13** ***6%***	40 *18%*	4 *2%*	32 *15%*	35 (10/16/9) *16%*	9 (9/0) *4%*	2 (1/1/0) *1%*	**56** ***25%***
Total mentions	*71* *13%*	*24* *5%*	*90* *17%*	*10* *2%*	*88* *17%*	*89* *17%*	*24* *5%*	*14* *3%*	*120* *23%*

The degree to which "sustainability" is required to be embedded in programmes varies considerably among the accreditation body's accreditation criteria. Both ABET and EUR-ACE only make a single reference to sustainability, in rather oblique ways. ABET's only mention of sustainability is as one of the "possible constraints" that is imposed on Engineering Design, where it defines the latter. It is listed (second last) among some 18 other possible *constraints* such as marketability, interoperability, accessibility and standards. EUR-ACE only mention sustainability "to deliver sustainable solutions for society, the economic and environment" in the context of masters level graduates requirement for "making judgements communications and team-working" (EUR--ACE, 2021).

The other three professional institutions considered elevate sustainability to a far more central role however. Engineers Australia mentioned sustainable or sustainability three times in its introductory description of the "mature, professional engineer"; as part of its "Stage 1 Competency Standard for Professional Engineer" (Engineers Australia, 2019), which it then sets out in tabular from under three headings (1. Knowledge and skill base; 2 Engineering application ability; 3. Professional and personal attributes). Sustainability requirements are highlighted among the first two of these. Engineers Ireland too in its previous (2014) accreditation criteria required sustainability input in "design" and under "ethics" programme outcomes (Engineers Ireland, 2014). However, while these remain in its latest (2021) iteration, it also incorporates a new seventh overall "Programme Area" under "Sustainability" (Engineers Ireland, 2021). This requires that students of accredited programmes must be both "introduced to specific sustainability concepts such as net zero carbon, resource efficiency, circular economy and whole-life cost", but also it is required that students "need to be aware of the global and multi-cultural context of their work." (Engineers Ireland, 2021) Recognising the global and universal imperative of the United Nation's Sustainable Development Goals (UN SDGs), the criteria require students be both exposed to them, and develop competences for achieving them.

Since its 2017 version of criteria, the Institution of Chemical Engineers also requires sustainability be embedded across the curriculum; as well as requiring it specifically as part of "embedded learning". It is also cited as part of "core", "design" and "ethical" imperatives, respectively (IChemE, 2017). The importance placed upon sustainability is reflected in the fact that the IChemE requires students of accredited programmes to "acquire the knowledge and ability to handle *broader* implications of work as a chemical engineer. These include sustainability aspects." (ICheme, 2017) The 2021 iteration includes all the above, but suggests an "increased emphasis on sustainability, consistent with IChemE's stated position on climate change" (IChemE, 2021). It too goes beyond a requirement for "not only the *technical* aspects of challenges such as waste, climate change, economic and environmental damage but *also* the *societal* impacts highlighted by the majority of the United Nations Sustainable Development Goals" (IChemE, 2021). "Cultural learning" is a new aspect of the IChemE's, 2021 iteration, where this is emphasized in relation to "sustainability", as well as three other areas of "health and safety", "ethics", and "diversity and inclusion" (IChemE, 2021). In this and other criteria descriptions, "sustainability" has almost universally replaced the older concept of "sustainable development", reflecting the wider scope, while in the case of the IChemE and Engineers Ireland there is a clear implication that there is an expectation to demonstrate how sustainability is *embedded throughout* the programme, including via a range of aspects. The earlier discussion may be of value here; a conception of sustainability which goes *beyond* sustainability related *skills* (technologies, LCA, etc.), but explicitly moves into sustainability *knowledge* and sustainability related *values* is required, and these attributes are sought to be demonstrated, in a way that cuts across the programme and the other eight categories in Table 1. While the UN SDGs are time limited (to 2030), their universal nature suggests that the institutions will also incorporate their successors, while their value lies, not as some set-in-stone everlasting definitive last word on sustainable development, but rather in their ability to facilitate student engagement in a way which may allow students envisage the *broader* complex, interconnected nature of sustainability imperatives (and to do so at various levels, including technical, ethical, equitable, economic, etc.), while also productively engaging with specific place-specific exemplars, and in the concrete aspects that each of the 17 SDGs may facilitate.

2.2.2.2. Equity/Equality Diversity and Inclusion (EDI/DEI). Equity or Equality, Diversity and Inclusion are recent additions to both IChemE and Engineers Ireland requirements, appearing in the most recent iteration of both. They relate to sustainability as articulated across a number of the UN's SDGs (e.g. #1, #5, #10, #16, #17), while also reflecting societal norms, as well as corporate imperatives across many of the organisations that chemical engineering graduates work for. Perhaps, given the greater diversity across engineering programmes and society historically in the USA, this is an area which has been more developed among ABET and across American universities and programs. This remains the case with the ABET criteria proposing to insert a definition for each of the three terms from its 2023–2024 iteration. There is an onus too on faculty, who, it is proposed "must demonstrate awareness and abilities appropriate to providing an equitable and inclusive environment for its students, and knowledge of appropriate institutional policies on diversity, equity, and inclusion." (ABET, 2022). Among an increasingly diverse and globalised student and workplace environment, IChemE (2021) proclaims that it "is strongly committed to the principles of equality, diversity and inclusion", and thus seeks that graduates of accredited programmes will "be able to adopt an inclusive approach to engineering practice and recognise the responsibilities, benefits and importance of supporting equality, diversity and inclusion". IChemE also highlights the normative aspects of engineering practice, while tying together aspects of sustainability, ethics and EDI in requiring that graduates understand that "an effective ethics culture includes how sustainability, economics, health and safety, equality, diversity and inclusion and professionalism are informed by and influence the ethical reasoning and behaviour of the professional engineer." (ICheme, 2021)

Engineers Ireland too highlights "equality, diversity and inclusion" as a new consideration from 2021 under professional and ethical responsibilities (Engineers Ireland, 2021). Engineers Australia in its 2019 criteria seek that graduates recognises "the value of alternative and diverse viewpoints" and can function "as an effective member or leader of diverse engineering teams, including those with multi-level, multi-disciplinary and multi-cultural dimensions". (Engineers Australia, 2019)

2.2.2.3. Ethics. Ethics is increasingly linked to sustainability across a number of accreditation criteria. EUR-ACE cite the "challenges facing our planet and society and the ever increasing need for engineers to ethically challenge their work for the benefit of society" (EUR-ACE, 2021), while ABET require graduate be able to "recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts." (ABET, 2022). Engineers Australia lists "Ethical conduct and professional accountability" as the first of six professional and personal attributes, citing its Code of Ethics (Engineers Australia, 2019). IChemE and Engineers Ireland take similar approaches, explicitly linking ethics and sustainability (as well as EDI, Health and Safety, etc.). Engineers Ireland (2021) does this through making "Professional and Ethical Responsibilities" one of its eight "Programme Outcomes", while IChemE (2021), as well as requiring ethics as "embedded learning", requires an institutional "ethics culture" to be evident whereby students learn to "integrate their knowledge and understanding" of core principles and ethical aspects to solve sometimes complex or novel problems.

2.2.2.4. The Global Engineer. All the institutions make mention of the need for a global outlook and contexts, in the context of an increasingly internationalised and globalised world, and its interconnected issues. As IChemE (2021) put it, the "increasing importance as the globalisation of engineering products and services demands greater confidence by employers in the skills and professionalism of the engineers they recruit".

2.2.2.5. Society, Societal and Social imperatives. The social responsibility and requirement to do societal good is evident across all the professional body's criteria, including in the sustainability context (e.g. under the "social" pillar of the three pillars model, as articulated by Engineers Ireland (2021), or the "societal impacts" of the SDGs in addition to as well as the technical, as referred to by IChemE (2021)). ABET (2022) mentions removing participation gaps to facilitate social justice, under the equity heading of DEI.

2.2.2.6. Multicultural imperatives. Cultural, cross-cultural and multicultural imperatives are included in most of the accreditation bodies' criteria. Engineers Australia (2019) cite the need for graduates to engage in diverse engineering teams, "including those with multi-level, multi-disciplinary and multi-cultural dimensions", while ABET (2022) cite the need to apply engineering design with consideration of cultural as well as other factors. Engineers Ireland (2017; 2021) require a knowledge and understanding of cultural issues under professional and ethical responsibilities, while citing the need to engage in communication effectively in international and multicultural contexts. IChemE (2021) meanwhile highlights the importance of cultural development of chemical engineering students themselves under the four pillars cited previously, including to support the effectiveness of their careers, while also being able to take into account cultural (and many other, e.g. societal, inclusion, environmental, codes of practice, etc.) considerations in their work.

2.2.2.7. Multi/Inter/Transdisciplinarity. All the institutions cite multidisciplinary endeavours and the need to engage in same, while some also mention interdisciplinarity as a requirement in the practice of engineering. Engineers Ireland (2017; 2021) appear strongest on this front requiring that students should have the opportunity to become involved in multidisciplinary projects which require them to draw upon technologies outside their immediate area of interest, while under "Teamwork and Lifelong Learning" programme outcome, the criteria require the development of the ability to work with a broad range of stakeholders in multidisciplinary settings. Given the perceived value of transdisciplinary approaches and ethos by EESD and ESD researchers, and given Clift's, 2006 exhortation (cited above) that sustainability/sustainable development is necessarily trans-disciplinary, this term is conspicuous by its absence, at least for now.

2.2.2.8. Complexity and Complex Systems engagement and understanding. Sustainability related issues are inherently complex, going beyond the merely technical to incorporate social, ecological, ethical, legal, political, etc. They are also normative, incorporate deep uncertainty and thus represent classically wicked problems in nature, requiring integrative approaches. This is well recognised by the professional bodies in their accreditation criteria.

Engineers Ireland (2021), under their programme outcome on "Problem Analysis" require the "the ability to integrate knowledge, handle complexity and formulate judgements with incomplete or limited information and considering professional responsibilities towards people and the environment", while Engineers Australia (2019) require that graduates appreciate "the formal structures and methodologies of systems engineering as a holistic basis for managing complexity and sustainability in engineering practice", and that through application, graduates may competently address "complex engineering problems which involve uncertainty, ambiguity, imprecise information and wide-ranging and sometimes conflicting technical and non-technical factors." The Australian body in its role description of the professional engineers cite that they are "responsible for bringing knowledge to bear from multiple sources to develop solutions to complex problems and issues, for ensuring that technical and non-technical considerations are properly integrated, and for managing risk as well as sustainability issues." (Engineers Australia, 2019)

EUR-ACE (2021) too require an "ability to identify, formulate and solve unfamiliar complex engineering problems that are incompletely defined, have competing specifications, may involve considerations from outside their field of study and non-technical – societal, health and safety, environmental, economic and industrial – constraints" while ABET (2022) require an ability to engage with complex engineering problems, which may involve "wide-ranging or conflicting technical issues, having no obvious solution, addressing problems not encompassed by current standards and codes, involving diverse groups of stakeholders, including many component parts or sub-problems, involving multiple disciplines, or having significant consequences in a range of contexts."

IChemE (2021) meanwhile acknowledge the requirement to integrate knowledge bases, such that graduates "will have the ability to integrate their knowledge and understanding of mathematics; science; computer-based methods; design; the economic, legal, social, ethical and environmental context; and engineering practice to solve problems, some of a complex nature, in chemical engineering" and "be able to apply the principles to the analysis of complex systems within a structured approach to safety, health and sustainability." They also require programmes to "encourage students to take a broad view when confronted with complexity arising from the interaction and integration of the different parts of a process or system" (IChemE, 2017; 2021).

It is hardly surprising therefore that engagement with complexity is a recurrent theme in accreditation criteria. This is added to however by two other factors; some bodies, most notably IChemE and Engineers Ireland use handling complexity as a marker for differentiation between bachelors and advanced/masters/chartered level graduates, while complexity is also taken to have a more resticted defined conception relating to technical process/engineering system complexity e.g. ABET (2022): "an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics". IChemE (2017; 2021): "the design portfolio must include a major design exercise which addresses the complexity issues arising from the interaction and integration of the different parts of a process or system [..requiring] the design of specific and complex equipment items to deliver a process or product objective, eg extruder, distillation column, etc;", or with Engineers Ireland (2021): "the ability to apply and where necessary adapt emerging technologies and data science to complex engineering problems."

3. Conclusions

It is clear from this snapshot of the accreditation criteria of a number of international accreditation bodies that there is a wide range of requirements and perspectives on how far and deep the sustainability imperative is envisaged. Chemical engineering programmes under the auspices of IChemE are subject to among the more rigorous and broadly conceived sustainability requirements in the formal professional education of graduates. The degree to which sustainability is broadly conceived, and the requirement for an integrated approach to various categories or attributes (as articulated in Table 1) up to and including the incorporation of the UN SDG's, also varies considerably among accreditation bodies. Moreover this is a moving target, with for example most recent iterations (of Engineers Ireland and IChemE) requiring criteria with more explicit integration of complexity and sustainability, as well as enhanced engagement and requirements around sustainability (including SDGs), and equity, diversity and inclusion.

3.1. A global view

These trends follow broader societal and corporate trends; from a purely financial perspective, the total shareholder return for "green leaders" was found to be two to three times higher than for laggards (McKinsey, 2022). Nevertheless, accreditation criteria trends towards broader sustainability imperatives are markedly less pronounced in the United States via the ABET criteria, or under the pan-European EUR-ACE umbrella. An exception here is in the area of equity, diversity and inclusion, where the US has traditionally been ahead of other places, and where there is a stronger emphasis on faculty engagement. And even though the IChemE has an international reach, there remains vast swathes of the chemical engineering world where such IChemE informed imperatives do not pertain. In China for example, who produce a significant number of the world's chemical engineers, supporting some 40% of the world's chemical industry output, it is still the case that chemical safety imperatives are seen as central to, and intimately linked with, conceptions of the "sustainable development" of the industry (Chen and Reniers, 2020; Motalifu et al., 2022). Although there are often longstanding government supported imperatives to incorporate socio-political and philosophical threads across higher educational programmes in China, this does not seem to be envisaged or incorporated in any integrated or integrative way (for example, through infusing Eastern philosophical context into chemical engineering practice). Even among ABET accredited programs in China, there appears to be little on broader sustainability related aspects across programmes (as described above) which would envisage sustainability as going beyond some traditional aspects of "green engineering" and "environmental engineering", which are themselves oftentimes coupled with process safety, although there has been significant progress in these areas among some programmes, supported (as elsewhere) by government, industry and societal drivers (Wu et al., 2021). Nevertheless, outside of "Process Safety and Environmental Protection" modules/courses, many chemical engineering programmes in both China and the USA appear to not go much beyond that in offering a range of traditional chemical engineering topics (Yao et al., (2021)), which would be easily identifiable within any mid twentieth century curriculum.

It does not necessarily follow through however that respective programmes across the chemical engineering world, or across the various engineering disciplines and regions universally provide graduates which are better equipped to deal with sustainability matters than others as a result of regional or discipline specific accreditation imperatives. EESD research outputs demonstrate some strong engagement in these issues across many programmes in the United States, for example, while programmes under IChemE auspices may still exhibit more traditional approaches and curricula. This is because accreditation criteria do take time to become embedded, while individual faculty engagement too can vary considerably in such matters. Nevertheless, and over time, relevant accreditation criteria can and do act as powerful drivers for change, evolution, and even transformation. While pioneering educators who seek to make a difference through embedding sustainability imperatives in their programmes and modules may do so in a way which embraces whatever text or requirements provided in their respective accreditation criteria, a more engaged and forward sustainability professional engineering accreditation requirement is nevertheless very helpful to such programmes, as it facilitates and commends such change, while protecting enthusiastic staff from potential criticism through providing formal and structural support.

Overall, a few key developments can be ascertained in the current review:

- the evolution and requirements for "sustainability" imperatives varies considerably among professional accreditation bodies
- where sustainability is being incorporated to a greater extent, there is a greater and increasing recognition of the need for a broader conception of sustainability, in a way which recognises interaction and integration with other sustainability related imperatives, for example around ethics, uncertainty, complexity, EDI, and recognition of interdisciplinary and global imperatives.
- This increased recognition is influenced by evolving societal imperatives, including among universities themselves, and across corporate workplaces, which promote associated industry imperatives around graduate attributes.
- In this context, the model of sustainability knowledge, skills and values (Gutiérrez Ortiz et al., 2021) may be useful, as the normative or values based basis of engineering practice is more explicitly recognised throughout and within curricula, in cross cutting ways alongside technical and knowledge based imperatives, such as in the practice of design.

3.2. Leading on sustainability as a recruitment tool

The question may arise as to whether respective accreditation bodies actually demand enough or too much of universities in terms of their respective sustainability imperatives. The answer to this is of course normative, and will vary depending on one's perspectives, while accreditation panellists will also take a more or less rigorous approach to seeing criteria implemented, based on their own personal interests and perspectives. Nevertheless, a strong sustainability ethos and underpinning, whereby programmes explicitly seek to integrate a broader consideration of sustainability imperatives, can itself act as a powerful marketing tool for the profession, including in attracting a broader and more diverse recruitment base, while marking out (chemical) engineering as being both of vital importance in addressing issues of increasing societal concern, while seeking to demonstrate leadership in this area.

3.3. Reflection on local experience

This certainly seems to have been the case in the programme of the author at University College Cork (UCC), where staff have for over a decade sought to embed and integrate sustainability imperatives across the programme, while promoting this as core to contemporary chemical engineering practice, including in external promotion. During this time, the Process and Chemical Engineering programme has established itself as consistently the most popular of all the university's engineering programmes, while students and graduates have almost without exception embraced this approach without resistance. During that time the programme and its students have won a number of IChemE sustainability awards (IChemE Sustainability Teaching Award (2016); Macnab-Lacey design project prize (2021)). The programme has also attracted an increasingly enhanced gender balance among students over that time, with over 40% of entering students being female in 2021. This coheres with research findings which suggest that females in particular are attracted to the prospect of making a positive difference in one's career choice (Alpay et al., 2008), while the social status associated with making a positive difference around sustainability challenges is an underlying motivation (Gille et al., 2021). University imperatives too, around integrating sustainability, the UN SDGs and inter- and transdisciplinary into programme across UCC (UCC (2018)), and UCC's green campus and sustainability agenda (Kirrane et al., 2020), also help support such initiatives from a top down level, while chemical engineering employers' requirements to go beyond the merely technical and display the attributes outlined in Table 1, provide a powerful and supportive environment for such developments.

3.4. Meeting and surpassing societal demands and expectations

Finally, wider societal imperatives, and in particular the concerns and drivers among school leavers who have never known a reality which has not promised a future of potentially catastrophic climate change and biodiversity loss, and whose working lives through mid-century and beyond will be dominated by these issues, are perhaps the most compelling drivers. Programmes which dogmatically stick to twentieth century conceptions of the engineer in this context will likely increasingly struggle to find relevance. Recognition of this was evident from the report of the European Convention on a meeting of leading European engineering bodies representatives in Paris on "Being an engineer tomorrow in Europe", where it was observed that students have strong expectation regarding sustainable development and societal change values, and engineering education needs to address these (cdefi, 2022). It was also suggested that today's students.

> "want to find a job but they expect a more sustainable way of life and they are concerned about the protection of the living world. They have a longer term perspective: they want to have an impact on the world and strive to implement more sustainable practices in their area. The impact of engineers on the world has also a greater importance today than thirty or forty years ago. The understanding of the various dimensions of their role and their integration into society is now part of the requirements of engineering education."

While it may seem self-evident from a disciplinary perspective that engineers will be required to address the issues that humanity faces, other disciplines will envisage the same, with some legitimacy. Thus, an outward and explicit recognition and engagement with the system complexity we face and hence the need for inter- and transdisciplinary approaches, in ethos as much as in operation, is urgently required. The value of chemical engineering, with its systems approach, has been to see the necessity of taking the wider view. In this way perhaps, chemical engineering has managed to stay centrally relevant, and attractive to school leavers in a way that a more conservative approach might lead to a diminution on perceived relevance. The fact that "sustainability engineering" programmes have not taken off or taken hold, is in good part as a result of traditional branches of engineering envisaging "sustainability" (with all its social, environmental and ethical considerations) as being an inherent part of engineering and the curriculum. Accreditation bodies are at the forefront of this, as they articulate the self-image of relevant professions across the global and in various regions. Evolution of accreditation criteria thus involves a co-evolutionary process with society at large; evolving with the very societies that engineers seek to serve, support and enhance.

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