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Embedding Sustainability In The Engineering Curriculum: Meeting The Requirements Of Professional Accreditation

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Professional accreditation agencies are increasing requirements on sustainability in engineering education as a response to ethical obligations, industry needs and emerging academic best practice. In 2021, Engineers Ireland increased sustainability requirements in new accreditation criteria. This paper reports on a thematic analysis carried out by Engineers Ireland on the self-assessment and achievement of these new accreditation criteria on sustainability. The analysis was conducted on the self-assessment reports from a large Irish University, referred to as University A hereafter. The results indicate that, for the purpose of meeting accreditation requirements, University A has interpreted sustainability in their programmes as either meeting the UN Sustainability Goals (SDG's) by mapping modules to the SDG's, or by aligning Programme Area (PA) 7 *Sustainability* of the Engineers Ireland accreditation criteria with the Engineers Ireland Programme Outcomes (PO's). The paper outlines the main themes and approaches identified across 17 engineering programmes and presents 2 case studies of how sustainability is embedded in engineering curricula in Ireland.

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1 INTRODUCTION

Engineers Ireland assess Engineering programmes in Higher Education Institutions (HEIs) in three main categories, Programme Outcomes (POs), Programme Areas (PAs) and Programme Management (PM). The assessment is outcome focussed, however professional accreditation agencies are increasing requirements on sustainability in engineering education as a response to ethical obligations, industry needs and emerging academic best practice (Beagon et al. 2021; DFHERIS 2021). In 2021, Engineers Ireland increased requirements on sustainability in their new programmatic accreditation criteria, specifically Programme Area 7 (PA7) *Sustainability,* becoming one of the first Washington Accord signatories to implement the new set of International Engineering Alliance (IEA) graduate attributes.

While there appears to be agreement on what the competences for addressing sustainability are (Wiek, Withycombe, and Redman 2011; Brundiers et al. 2021; Beagon et al. 2022) the ways and means they are adopted and embedded into engineering curricula is the subject of further investigation. Building on the work of ASTEP 2030 in identifying the ways that sustainability is embedded in engineering programmes (Kövesi et al. 2021; Beagon et al. 2022), this paper reports on a thematic analysis on the self-assessment and achievement of sustainability within the curricula of a large Irish Technological University, referred to as University A hereafter. The analysis was conducted on the self-assessment reports provided by University A seeking programmatic accreditation with Engineers Ireland. The paper outlines the main themes identified across 17 engineering programmes in 4 faculties at University A. Two case studies of exemplary programmes are also presented based on the outcome of the thematic analysis.

2 LITERATURE REVIEW

Accreditation is undertaken to ensure that education meets accepted standards and best practice and is the primary Quality Assurance (QA) process used to ensure the suitability of an educational programme as the entry route to a profession such as engineering (Augusti 2007). In Ireland, the professional accreditation of engineering programmes is undertaken by Engineers Ireland, the professional body for engineers. The Accreditation Board of Engineers Ireland is responsible for overseeing the accreditation process, making accreditation decisions, and recommending changes to the Accreditation Criteria.

Engineers Ireland's accreditation involves a periodic audit of engineering programmes by a visiting panel against the Accreditation Criteria. As the process is outcome-focused, the panel reviews a variety of evidence to ensure that graduates' attributes are consistent with the accreditation criteria. The criteria are aligned with

the education standards for the professional titles of Chartered Engineer, Associate Engineer, and Engineering Technician (Conlon 2008).

The first Engineers Ireland accreditation was in 1982 (Engineers Ireland 2021) and there are currently more than 200 accredited programmes in Ireland. Extant literature demonstrates changes in accreditation criteria have an impact on engineering programme curricula. For example, ethics was introduced as a programme outcome more than 20 years ago. Subsequent research has demonstrated a less siloed and more holistic approach to ethics in engineering education (Homan 2020; Martin 2020). However, there are still different attitudes and cultural approaches taken to the technical & non-technical elements of the accreditation criteria in Irish Engineering Education (Martin 2020).

The Accreditation Criteria 2021 (Engineers Ireland 2021) is a comprehensive update on the 2014 version (Engineers Ireland 2014). A significant change in the 2021 criteria relates to a requirement to demonstrate sustainability in programme curricula. Specifically, graduates should have an understanding and appreciation of the environmental, social, and economic impacts of their judgments and to promote the principles and practices of sustainable development (Engineers Ireland 2021). Sustainability relates to the role of the engineer in society and professional conduct in terms of acting with honesty, integrity, and objectivity. Prior to the new criteria, where sustainability was addressed in engineering programmes in Ireland, it was often siloed within a single module (Homan 2020; Martin 2020).

Now, engineering education needs to be viewed in the context of the environment, to ensure that graduate engineers understands that they have responsibilities to society, the environment, and to their profession in general. It is more than a decade since Byrne and Fitzpatrick (2009) called for sustainability to become the context of engineering practice by:

" incorporating a sustainability informed ethos throughout engineering curricula" -p.1

by both professional institutions and educators. Furthermore, this should be accompanied by a commitment to the ethical usage of technology and data which is an important component of the increased use of data science, analytics, and emerging technologies (Engineers Ireland 2021). This is reflected in changing approaches to the accreditation of professional engineering programmes.

Sustainability means:

"reducing energy consumption and greenhouse emissions, to avoid depletion and degradation of natural resources, to ensure the needs of today's generations without jeopardising the needs of future generations" (Ghobakhloo et al. 2022) -p.12

However, including new technologies in the engineering programme curricula in isolation, is not sufficient. Complementary approaches such as sustainable thinking, circular intelligent products and upskilling and reskilling are also needed (Ghobakhloo et al. 2022).

At a macro policy level, it is widely recognised that the UN Sustainable Development Goals are important influences on engineering education (Kasinathan et al. 2022; Leng et al. 2022; Zeb et al. 2022). At a European level, two important strategic policy directions which are influencing the development of sustainability in engineering education are the Green and Digital transformations. The EU Green Deal (Kasinathan et al. 2022) demonstrates the necessity to transition to a more circular economy and increased reliance on sustainable resources, including energy (Xu et al. 2021). The EU digital agenda (European Commission 2015) will impact innovation and education for the next generation (Alexa, Pîslaru, and Avasilcăi 2022; Renda et al. 2022). Renda et al (2022) relates the UN SDGs to advances in engineering education in the realm of ethics and humanism. Looking to the future, engineering programmes should change their content after engagement with academic and industry (Cuckov et al. 2022).

In Ireland, research focusing on engineering accreditation (Homan 2020; Martin 2020; Chance et al. 2021; Byrne 2023; Doyle Kent 2021) demonstrates an opportunity to examine if changes made to the Engineers Ireland 2021 accreditation criteria has highlighted the sustainability activities embedded in the engineering curriculum.

3 METHODOLOGY

Seventeen programmes were assessed in the thematic analysis, these included Civil, Mechanical, Electrical, Electronic, Energy, Biomedical and Chemical Engineering programmes in University A. In Ireland, programmes are described by the National Framework of Qualifications (NFQ) as set out by Quality & Qualifications Ireland (QQI). The analysis included Higher Certificates (level 6), Ordinary Bachelor's degrees (level 7), Honours Bachelor's degrees (level 8) and Master's degrees (level 9). The method used to identify themes was drawn from Braun & Clarke (Braun and Clarke 2006), who recommend conducting thematic analysis in 6 steps, which are outlined in Table 1.

Table 1. Braun & Clarke (2006) method for thematic analysis

	Step	Action	Output
1	Become familiar with the data	Read and re-read the submission documents	Preliminary ideas about codes
2	Generate initial codes	Organise data in a meaningful way	Coding of each document separately
3	Search for themes	Examine codes to see if some fit together into a theme	Codes organised into broader themes that say something specific about the research
4	Review themes	Modify and develop the preliminary themes	More organised and logical set of themes and sub-themes
5	Define themes	Identify what each theme is saying	Thematic map illustrating relationships between themes along with a narrative
6	Write-up	Compile report	Findings

The self-assessment documents were initially reviewed, and a set of search terms were selected to help identify relevant clusters of text for coding. Documents were searched for the keywords *"sustain", "green", "environmental", "SDG", "circular economy"* and *"climate"* respectively. In step 2, a set of codes were generated and are presented in Table 2.

Table 2. Codes identified in step 2 of Braun & Clarke's method

Code	Description
M-SDG	SDG's were mapped to particular modules within a programme.
M-PA/PO	PA areas were mapped to programme outcomes highlighting how Programme outcomes were mapped to Programme Area 7.
S-SP	Description of where sustainability is in the university's strategic plan.
S-RE	Description of where sustainability is in the university's regional contribution.
SCM - PO	A module specifically addressing sustainability was identified as a strong contributor to a programme outcome.
SCM - PA	A module specifically addressing sustainability was identified as a strong contributor to a programme area.

Following the identification of codes, a set of subcodes were generated, particularly to examine the codes SCM – PO, and SCM – PA. The PO's can be thought of as being divided into 4 technical outcomes, including PO1 *Knowledge & Understanding*, PO2 *Problem Analysis*, *PO3 Design* and *PO4 Investigation,* and non-technical outcomes including *PO5 Professional and Ethical Responsibilities, PO6 Teamwork & Lifelong learning, PO7 Communication* and PO8 *Management*. The PA's which emerged from the thematic analysis where PA6 *Engineering practice* and PA7

Sustainability. The summary of the subcodes considered for the thematic analysis are presented in Table 3.

Table 3. Summary of subcodes identified in stage 2 of Braun & Clarke's method

Subcode	Description
SCM - PON	A module specifically addressing sustainability was identified as a strong contributor to a programme outcome N.
SCM - PAN	A module specifically addressing sustainability was identified as a strong contributor to a programme area N.

4 RESULTS

Table 4 illustrates how each Programme's (PG's) self-assessment report compared across the various codes identified. As mentioned in the methodology section, a cluster of codes in SCM-PO and SCM-PA were identified and resulted in a set of subcodes being developed to explore these codes in more detail.

Table 4. Coding density by discipline and additionally by NFQ level

	Programme (PG)										
Code	PG1	PG2	PG3	PG4	PG5	PG6	PG7	PG8	PG9	PG10	PG11
M-SDG	4	2	2	1	1	1	1	3	1	1	1
M-PA/PO	0	1	1	1	1	0	0	0	0	0	0
S-SP	0	1	1	1	1	0	0	0	0	0	0
S-RE	0	1	1	1	1	0	0	0	0	0	0
SCM -PO	11	5	4	2	2	3	13	9	1	10	18
SCM -PA	10	0	0	0	0	7	16	14	6	11	21

Table 5. illustrates the breakdown of the strong contributor modules to each PO and PA identified in the self-assessment reports. These codes clustered on PO5, *Professional & Ethical responsibilities* and PA7 *Sustainability* which is unsurprising as an engineer's responsibility to protect the environment is explicitly written in the Engineers Ireland Code of Ethics (Engineers Ireland 2023)**.** Of interest is the cluster of codes in PO3 *Design,* 12 modules identified as strong contributors to sustainability were mapped to this PO, implying that Engineering Programmes at University A use design modules to convey the importance of sustainability to students, this implication is bolstered in the case studies presented later.

Table 5. Sub-coding density by discipline

Subcode	PG1	PG2	PG3	PG4	PG5	PG6	PG7	PG8	PG9	PG10	PG11
SCM - PO1	0	0	0	0	0	0	0	0	0	1	2
SCM - PO2	0	1	1	0	0	0	2	1	0	2	2
SCM - PO3	0	0	0	1	1	1	4	1	0	2	2
SCM - PO4	0	0	0	0	0	0	0	1	0	0	5
SCM - PO5	6	4	3	1	1	2	6	3	1	4	5
SCM - PO6	2	0	0	0	0	0	0	2	0	0	1
SCM - PO7	2	0	0	0	0	0	0	1	0	0	0
SCM - PO8	1	0	0	0	0	0	1	0	0	1	1
SCM - PA2	1	0	0	0	0	0	0	0	0	0	0
SCM - PA6	1	0	0	0	0	0	0	0	0	0	0
SCM - PA7	8	0	0	0	0	7	16	14	6	11	20

4.1 Theme 1: Commitment to SDGs at a strategic level

All programmes declare commitment to the SDGs at a strategic level. An analysis using the EU KnowSDGs (https://knowsdgs.jrc.ec.europa.eu/) tool is used by programmes used to identify the key SDGs. Furthermore, all programmes include statements of support of SDGs at both departmental and faculty level.

A selection of rich data supporting theme 1:

". . . aims to bring about a sustainable and fundamental change in behaviour and influence a best practice culture across the University, on all campuses through embracing the UN SDGs."

". . . committed to embracing Education for Sustainable Development as an integral element of the SDG on quality education as a key enabler of all the other SDGs"

". . . by 2030 ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and nonviolence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development"

4.2 Theme 2: Alignment with Programme Outcomes (POs)

Programme Outcomes are broad statements identifying learning parameters, content, and relationships between content areas. Many of the programmes under review were designed prior to the 2021 Engineers Ireland criteria, therefore it is reasonable that the SDGs were not explicitly included in the programme design process. However, there is evidence of alignment of elements of sustainability across all PO's. This is particularly evident in relation to *PO2 Problem Analysis, PO3 Design, PO4 Investigation and PO5 Professional and Ethical Responsibilities.*

4.3 Theme 3: **Alignment with new programme area of sustainability**

Programme Areas are necessary to facilitate the engineering graduate's achievement of the Programme Outcomes. An example of the interpretation of Engineers Ireland PO's to PA7 extracted from a self-assessment report can be seen in Table 6.

Table 6. Example of the interpretation of EI POs to PA7

Engineers Ireland PO	Example interpretation of PA7
Knowledge and Understanding	Introduction to SDGs and relevance to engineering practice, manufactured products and project outputs
Problem Analysis	Query the sustainability of existing assumptions and processes
Design	Design for sustainability. Impact of SDGs on future design requirements
Investigation	Acknowledging complexities and looking for links and synergies in problem solutions.
Professional & Ethical Responsibilities	Consideration of relevant SDGs in educational development and professional practice.
Teamwork & Lifelong Learning	Inclusion of external factors and users in the commitment to sustainable action in engineering activities.
Communication	Promoting dialogue and negotiation across diverse groups in addressing SDGs.
Engineering Management	Involving people in joint analysis, planning and control of decisions.

5 SUMMARY AND ACKNOWLEDGMENTS

An outcome of the analysis of codes and subcodes were the identification of 3 exemplary programmes at University A in terms of how sustainability was being embedded within the taught content of the programme, an Energy programme delivered at Bachelor level and 2 Mechanical programmes delivered at Bachelor and Master level, the latter of which will be taken together.

5.1 Energy Engineering programme

In this programme, 20 codes were identified presenting modules as strong contributors to PA7 *Sustainability*. Four modules in particular, contributed 72% of this coding density. This is not a prescribed approach to addressing PA7, however the coding indicates that modules addressing PA7 were also strong contributors to PO4 *Investigation and* PO5 *Professional & Ethical Responsibilities.* Implying that sustainability is embedded in experimental design and simulation. Of particular note is the 15 ECTS work placement module, where students get first-hand experience of their professional and ethical responsibilities as part of the ten-week placement.

Typically, students undergo specific training for the company they are placed in, and this will often reinforce these responsibilities. Working under the guidance of a mentor, students get continual feedback regarding their professional performance and expectations as engineers, helping students to grow personally and professionally.

The new programme area PA7 *Sustainability,* is evidenced across all four years of the programme with a higher proportion in years 2 and 4. With respect to assessment, 77% of modules with codes contributing to sustainability in POs, are assessed fully via continuous assessment. Similarly, 75% of modules contributing to PA7 are assessed fully via continuous assessment. A first-year foundation module of particular interest related to Climate Change & Energy and contributes to PA7 as well as *PO1 Knowledge and Understanding, PO2 Problem Analysis, PO4 Investigation* and *PO7 Communication.*

5.2 Mechanical Engineering programmes

In these programmes, 16 codes were recorded relating to a module specifically addressing sustainability being identified as a strong contributor to PA7 *Sustainability*. This is not a prescribed approach to addressing PA7, however the coding indicates that modules addressing PA7 were also strong contributors to *PO2 Problem Analysis, PO3 Design, PO5 Professional & Ethical Responsibilities* and *PO8 Engineering Management* with thirteen codes identified relating to a module specifically addressing sustainability being identified as strong contributors. This suggests that while Sustainability is a Programme Area rather than a Programme Outcome, it permeates the Programme Outcomes.

Of particular note with regard to strong contributors to PA7 are the capstone design project on the Master's Programme, a 30 ECTS module in which students must consider all relevant societal impacts, including environmental impacts of their designs within the project thesis and the capstone design project on the Bachelors Programme (a 10 ECTS module where students must critically assess the project against appropriate design, safety, commercial and ethical criteria). Sustainability is evidenced across years 1,2 and 4 of the Bachelor programme with a particularly strong emphasis placed on sustainability in the Master programme, with 89% of modules contributing to sustainability being assessed through course work; including continuous assessment, lab work and reports. Only 3 modules contributing to sustainability contain a written examination and in no case is this 100% of the assessment on these modules.

5.3 Conclusions

The main findings were that University A made a strong commitment to align all programmes to the SDGs at a strategic level, embedded sustainability across multiple POs and identified strong contributor modules to *PA7 Sustainability* in a similar approach to that of the assessment of POs.

5.4 Limitations

A limitation of this study is that self-assessment reports are exactly that, self-assessed measures of achievement. In the estimation of Engineers Ireland, often individual academics underestimate their achievements in their self-assessments, and much more detail can be found in the individual evidence folders, which contain among other things, exam scripts, external examiner reports and module descriptors, as well as supporting evidence provided at accreditation visits and captured in the panel reports, which are prepared by external academics and industry representatives. There is a richness of data to explore on how sustainability is embedded in these programmes that goes far beyond the self-assessment reports that lies outside the scope of this paper.

5.6 Recommendations & future work

This paper is not conceived as a final product, but as an initial step in a wider research project. It demonstrates the accreditation process can now capture best practice examples of how sustainability is being embedded in engineering curricula across Ireland. It may be tentatively concluded that there has been an increase in awareness of the SDGs and sustainability practices in engineering education. These findings, however, do not establish a causal link between the new accreditation criteria and an increase in sustainability in engineering education. This would require a review of the self-assessment reports longitudinally to assess the relative influence of the previous Engineers Ireland criteria, as well as the mission statement of the University at the last accreditation visit. Further research is recommended, specifically in-depth interviews with accreditation panellists and the programme team would provide an understanding of the perceived gaps in the self-assessment reports, expansion of the dataset to include all HEI's who have been assessed against the 2021 accreditation criteria, and a review of the additional programme evidence provided in the submission for accreditation. These findings will be presented to the Engineers Ireland accreditation board and form part of the conversation about how the Engineers Ireland accreditation criteria are reviewed to reflect best practice in engineering education.

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