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Engineering Education 5.0: A Qualitative Case Study on How Accreditation in Engineering Programmes at a Higher Education Institution in Ireland Prepare Students for Industry 5.0

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Education is entirely my own work, and that I have exercised reasonable care to ensure that the work is original and have conformed to the regulations on the use and declaration of Generative AI, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work. I hereby certify that no Generative Artificial Intelligence (Gen AI) tools have been used in the creation of the thesis.

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List of Presentations Associated with this Study

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Abbreviations

ABET	Accreditation Board for Engineering and Technology
AEng	Associate Engineer
AI	Artificial Intelligence
ASCE	American Society of Civil Engineers
CAQDAS	Computer-Assisted Qualitative Data Analysis Software
CEng	Chartered Engineer
CHEER	Cambridge Handbook of Engineering Education Research
CPD	Continuous Professional Development
DBER	Discipline-based education research
DCU	Dublin City University
ECPD	Engineers' Council for Professional Development
EDI	Equality, diversity, and inclusion
EER	Engineering education research
EIAC	Engineers Ireland Accreditation Criteria
ENAEE	European Network for Accreditation of Engineering Education
ENQA	European Association for Quality Assurance in Higher Education
EQF	European Qualifications Framework
EUA	European Universities Association
HEI	Higher Education Institute
ICE	Institution of Civil Engineers
ICF	Informed Consent Form
IEA	International Engineering Alliance
IEE	Institution of Electrical Engineers
IGAESS	Integrating Graduate Attributes to Enable Student Success
IHEER	International Handbook of Engineering Education Research
IMechE	Institution of Mechanical Engineers
IP	Intellectual Property
JABEE	Japan Accreditation Board for Engineering Education
NDA	Non-disclosure agreement
NBA	Indian National Board of Accreditation
NFQ	National Framework of Qualifications
PA	Programme area
PARN	Professional Body Accreditation in HEIs in Ireland
PBL	Project Based Learning
PLS	Plain Language Statement

PO	Programme outcome
QA	Quality assurance
QE	Quality enhancement
QAG	QA guidelines
RTA	Reflexive thematic analysis
SAR	Self-assessment report
SEFI	European Society for Engineering Education
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNSDG	United Nations Sustainable Development Goals

Abstract

This study examines how engineering education in a HEI in Ireland, shaped by professional accreditation, prepares graduates to meet the emerging challenges of Industry 5.0. Building on prior research, it introduces a new model for Engineering Education 5.0, which comprises seven core features: technical competency, sustainability, ethics and social impact, collaboration, educational approach, global and cultural awareness, and holistic and human-centric values. The study applies Ball's (1993) policy cycle to trace how priorities are formed across contexts of influence, text production and practice. Data include interviews with Engineers Ireland accreditation board members, Engineers Ireland's 2021 Accreditation Criteria, and programme self-assessment reports. Analysis indicates strong alignment with engineering fundamentals, endorsement of lifelong learning, and increasing attention to ethical responsibility. Significant gaps nevertheless emerge. Artificial intelligence and other emerging technologies are referenced unevenly, with limited attention to responsible use. Sustainability is often operationalised as technical compliance rather than systems thinking and design foresight. Collaboration is commonly framed as teamwork, with weaker emphasis on transdisciplinary problem solving. Human-centricity is present in discourse but constrained by limited explicit commitments to inclusion and accessibility, and by the accreditation body's restricted remit over pedagogy. Integrating these findings, the thesis refines the original seven-feature model into a nine-feature Engineering Education 5.0 framework: technical competency; AI literacy and technical responsibility; sustainability; ethics and social impact; transdisciplinary collaboration; educational approach; global and cultural perspectives; holistic and human-centricity; and human capabilities. The thesis demonstrates the model's diagnostic value and shows how accreditation both stabilises traditional competencies and selectively translates emerging expectations. It concludes that Industry 5.0 readiness cannot be achieved through accreditation alone, and calls for coordinated action by professional bodies, educators, institutions and industry to embed responsible AI, inclusive practice and sustainability across curricula and assessment.

L. O'Gorman (2025)

Chapter 1: Introduction

1.1 Introduction

The relationship between technological innovations and engineering education has developed through chronological phases, known as industrial revolutions, with each period marked by mutual influence and adaptation (Doyle-Kent, 2021). The latest revolution, known as Industry 5.0, is described by an EU policy brief titled “Industry 5.0: Towards a sustainable, human-centric and resilient European industry” (Breque, de Nul and Petridis, 2021). The core objectives of Industry 5.0 outlined in this seminal document include transitioning from a profit-centric industrial paradigm to one that prioritises societal, environmental, and economic benefits; addressing pressing challenges such as climate change, social inequality, and technological disruption through innovation and collaboration; and fostering investments in skills development, education, and human-machine synergy to empower the workforce within an evolving industrial landscape. Ultimately, this vision calls for stakeholders across industry, academia, and government to collaborate in shaping a future where technological progress is aligned with social and environmental priorities. Engineering education is beginning to adapt to meet the needs of Industry 5.0 (Gürdür Broo, Kaynak and Sait, 2022).

Engineering programmes are designed, developed, and delivered by Higher Education Institutes (HEIs). The emergence of professional accreditation bodies for engineering is closely linked to the recognition of engineering as a distinct profession. Over time, these bodies have developed to ensure the quality, relevance, and ethical practice of engineering education and professional standards (Jurado *et al.*, 2005; Akera *et al.*, 2019). In Ireland, Engineers Ireland is the approved body for awarding professional titles and accrediting engineering education programmes. Accreditation by Engineers Ireland provides graduates with internationally recognised qualifications, enabling them to pursue global mobility and employment opportunities. The most recent iteration of Engineers Ireland Accreditation Criteria (EAIC) (Engineers Ireland, 2021) sets out the standards required for professional titles such as Chartered Engineer, Associate Engineer, and Engineering Technician. In this updated version, the criteria ensure compliance with international agreements, address societal and industry needs, and promote sustainability, diversity, and ethical practices. The EIAC document is a foundational guide for maintaining and enhancing engineering education quality in Ireland.

This research was inspired by the two aforementioned key publications: Breque, de Nul and Petridis (2021), which articulated the vision of Industry 5.0 and Engineers Ireland (2021), which set out updated national accreditation criteria for engineering education. Rather than treating these texts as neutral or purely technical artefacts, the study approaches them through a social constructionist lens, recognising them as discursive instruments that shape understandings of engineering education and professional identity. Accordingly, the research focuses on how engineering education in Ireland prepares graduates for the challenges of Industry 5.0, and more specifically on how Industry 5.0 is constructed through accreditation practices within a Higher Education Institution (HEI).

This chapter presents the justification for the research. It begins by providing an overview of the industrial revolutions to date, along with the parallel developments in engineering education. This is followed by an examination of the relationship between accreditation bodies and engineering education. A positionality statement is then presented, followed by the articulation of the research focus and question. Finally, the chapter concludes with an outline of the thesis structure.

1.2 The evolution of industrial eras and engineering education

The evolution of engineering as a profession and the corresponding advancements in engineering education have been profoundly shaped by successive industrial revolutions. Each revolution introduced transformative technologies and methodologies, necessitating a reassessment of engineering practices and educational paradigms (Jørgensen, 2006). According to the *Oxford Learner's Dictionaries* (2023), an industrial revolution is defined as "a great change in conditions, ways of working, beliefs, etc., affecting large numbers of people," which Deane (1979) argues results in significant social and economic shifts.

Although the term 'industrial revolution' is commonly used, it is acknowledged as a Western social construct (Bezanson, 1922; Deane, 1979). Discussions have often prioritised a technologically deterministic perspective, which reduces societal change to the inevitable outcome of innovation. This approach tends to marginalise the role of human agency, politics, and culture in shaping the development and application of technologies (Smith and Marx, 1994). Michelsen (2020) posits that the term is propagandistic, promoting technological enthusiasm and industrial change.

Despite its contested nature, the term 'industrial revolution' is employed in this thesis as it remains widely recognised and provides a useful framework for discussing associated developments in engineering education. To date, there have been five industrial revolutions, each characterised by major technological advancements (Industry 1.0–5.0). A timeline including the major technological advancements of the five industrial revolutions is shown in Figure 1-1.

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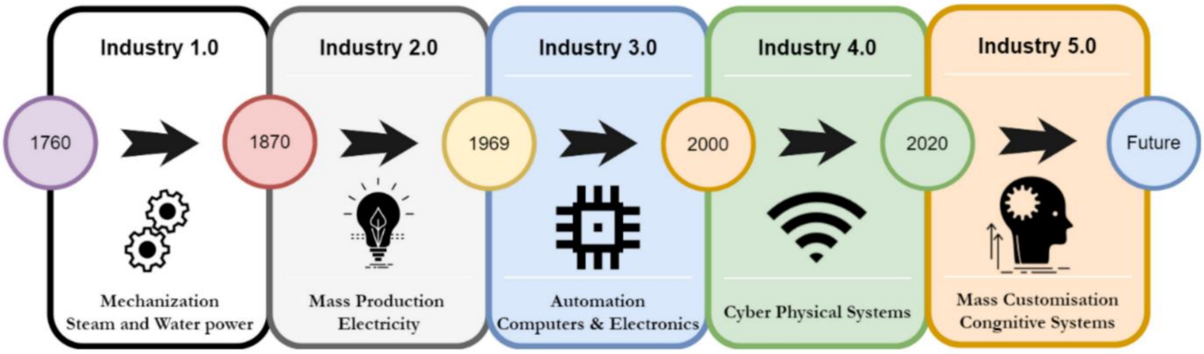

Figure 1-1: Timeline of Industry 1.0 to 5.0 (Ahmad *et al.*, 2022)

1.2.1 First industrial revolution

The first industrial revolution or Industry 1.0 (c. 1760), marked the start of mechanisation with the development of steam engines and the first mechanical manufacturing facilities (Kadir, 2020). Steam engines powered mass production, mechanisation, and urbanisation, enabling large-scale production and growth in transportation, textiles, and urban areas (Minculete, Bârsan and Olar, 2021). These advancements created a demand for a workforce skilled in both theoretical knowledge and practical application. In response, institutions such as the École Polytechnique in France and early engineering programmes in British universities introduced structured curricula that combined scientific principles with hands-on training (Borrego, Foster and Froyd, 2014). This era revolutionised industries and saw the formalisation of engineering as an academic discipline, as universities adapted to support the needs of fast-growing industrial economies (Kyne, 2021).

1.2.2 Second industrial revolution

The second industrial revolution, or Industry 2.0, at the start of the twentieth century, is characterised by the proliferation of mass production and electrification (Friedel and Israel, 2010). Innovations such as the electric light bulb and the assembly line made goods more accessible and transformed factories into highly productive workplaces (Royston, 2015; Bhandurge and Bhide, 2021; Xu *et al.*, 2021). Other advances, for instance, the first transatlantic phone call in 1927 changed views on communication and trade (Gherardi, 1927). This period saw rising capitalism and the growth of unions, as well as increased automobile use, which affected urban planning and pollution (Klingenberg, Borges and do Vale Antunes Jr, 2022). As this era required a deeper understanding of scientific principles, such as electricity, and magnetism, thermodynamics, and materials science, it elevated the prestige of engineering professions. These principles were integrated into laboratory-based learning at universities in order to prepare students to tackle the scientific and engineering challenges of the time (Murthy and Page, 2023).

1.2.3 Third industrial revolution

The third industrial revolution, Industry 3.0, began in the late 1960s, and this era was marked by the integration of telecommunications and automation into production processes due to the invention of transistors and integrated circuits. Engineering education responded by embracing globalisation, fostering academic mobility, and transitioning to international educational standards (Das, Kleinke and Pistrui, 2020). As technology advanced, engineers were required to consider how interconnected components interacted within broader contexts, particularly for large-scale projects like space exploration or advanced manufacturing systems (Klingenberg, Borges and do Vale Antunes Jr, 2022). The introduction of systems thinking into engineering programmes marked a shift from focusing solely on individual components or disciplines to addressing the complexity of entire systems. Engineering curricula also expanded to include interdisciplinary approaches, equipping graduates to address multi-faceted challenges (Murthy and Page, 2023).

1.2.4 Fourth industrial revolution

Industry 4.0, the fourth industrial revolution, emerged in Germany at the Hannover Fair in 2011 (Culot *et al.*, 2020). Known as the cyber-physical revolution (Majid *et al.*, 2019), it integrates computation with physical processes, featuring connected devices, smart machines, and enhanced information exchange (Lee, 2008). In recent years, this transformation has streamlined manufacturing, boosting efficiency and organisational performance (Nahavandi, 2019; Madsen and Berg, 2021). Key technologies in Industry 4.0 include the Industrial Internet of Things, Additive Manufacturing, Mixed Reality, Artificial Intelligence (AI), Digital Twins, Collaborative robots or Cobots, Autonomous Systems, and Big Data, which have collectively reduced costs in production, logistics, and quality management over the past decade (Nahavandi, 2019). To meet the demands of Industry 4.0, engineering education had to adapt and began to incorporate computer science, software engineering, and digital systems, reflecting the growing importance of these fields in engineering. Industry 4.0 also saw the increase of concepts such as lifelong learning, adaptability, and interdisciplinary collaboration into engineering programmes, and they were perceived as essential skills for engineers in a rapidly changing technological landscape (Froyd and Lohmann, 2014).

1.2.4.1 Industry 4.0 challenges

Although the progression to Industry 4.0 brought innovations, it also brought challenges spanning industrial concerns, the engineering profession, and engineering education. Industrial concerns centre around technological integration and complexity, whereby advanced technologies were integrated into existing processes, proving complex, often leading to interoperability issues and increased system vulnerabilities (Gürdür Broo, Kaynak and Sait, 2022). Also, the emphasis on automation and smart technologies in Industry 4.0 led to concerns about the diminishing role of human workers, potential job displacement, and the need for redefining human contributions within highly automated environments (Doyle-Kent, 2021). While Industry 4.0 focused on efficiency and productivity, it often overlooked environmental sustainability and societal well-being, necessitating a more holistic approach to industrial development (Özdemir and Hekim, 2018).

For the engineering profession, rapid technological advancements required engineers to acquire new competencies in digital technologies, data analytics, and systems integration, leading to a significant skills gap in the workforce (Michelsen, 2020). Engineers also faced increased pressure to consider the ethical implications of deploying advanced technologies, particularly those concerning data privacy, security, and the societal impact of automation (Ghobakhloo *et al.*, 2022). Furthermore, the complexity of Industry 4.0 systems necessitated collaboration across various disciplines, disrupting traditional engineering roles and requiring a more integrated approach to problem-solving (Ciolacu *et al.*, 2023).

Challenges in engineering education occurred when educational institutions struggled to update curricula rapidly enough to keep pace with technological advancements, resulting in graduates who were not fully prepared for the demands of Industry 4.0 (Lantada, 2020). Providing students with hands-on experience in advanced manufacturing technologies also proved problematic due to the high costs and rapid obsolescence of equipment (Mummolo, Browne and Rolstadås, 2023). Furthermore, the need for continuous skill development became more pronounced, highlighting deficiencies in traditional engineering education models that did not emphasise lifelong learning and adaptability (Hazrat *et al.*, 2023).

1.2.5 Fifth industrial revolution

In response to these challenges, the fifth industrial revolution, or Industry 5.0, began to emerge in the late 2010s, emphasising a human-centric approach that integrates human creativity and expertise with advanced technologies, prioritises sustainability, and seeks to enhance societal well-being (Fraga-Lamas, Lopes and Fernández-Caramés, 2021). This move reflects a shift towards more resilient, adaptable, and ethically responsible industrial practices (Nahavandi, 2019; Simion, Avasilcai and Alexa, 2021; Choi *et al.*, 2022; Coronado *et al.*, 2022). The term Industry 5.0 is increasingly gaining recognition among engineers and academics, although ongoing debates persist regarding whether it represents a genuine industrial revolution or merely an evolutionary extension of Industry 4.0. The definition of Industry 5.0 adopted for this study is that proposed by the European Commission, as it is gaining considerable recognition and is frequently cited in academic and professional discourse:

> *Industry 5.0 recognises the power of industry to achieve societal goals beyond jobs and growth to become a resilient provider of prosperity, by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the centre of the production process (Breque, De Nul and Petridis, 2021, p.14).*

This definition builds on the understandings of Industry 4.0 technologies, but with an explicit emphasis on human-centricity, sustainability, and resilience. Other definitions of Industry 5.0 emphasise its departure from the traditional Industry 4.0 paradigm by focusing on the reintegration of human creativity and craftsmanship into industrial processes. Rada (2018) conceptualises Industry 5.0 as a movement that brings humans back to the centre of industrial production, advocating for a synergy between human intelligence and advanced technologies to create a more sustainable and personalised manufacturing environment. Similarly, Doyle-Kent (2021) highlights the role of collaborative robots, or cobots, in facilitating a human-centric approach that not only enhances productivity but also addresses societal challenges by promoting safer and more adaptable work environments. These perspectives underscore Industry 5.0's alignment with the evolving needs of society and industry, prioritising human well-being and sustainable development.

As with previous industrial revolutions, engineering education must evolve to remain aligned with the principles of Industry 5.0. Engineering education is, therefore, expected to further integrate aspects of ethics, sustainability, and human-centric design, preparing engineers to work alongside intelligent systems and address complex global challenges.

1.3 Engineering education and professional accreditation

Engineering emerged as a distinct profession during the eighteenth and nineteenth centuries, spurred by industrialisation and the need for technically skilled individuals to design, build, and maintain critical infrastructure. Examples of the formation of professional institutions include the Institution of Civil Engineers (ICE), founded in London in 1818, marking the establishment of the first professional engineering body. It aimed to provide recognition for qualified civil engineers and promote engineering as a profession (ICE, 2023). Other branches of engineering followed suit, such as the Institution of Mechanical Engineers (IMechE) in 1847 and the Institution of Electrical Engineers (IEE) in 1871. These organisations initially focused on membership rather than formal accreditation, but laid the groundwork for standards in engineering education and practice.

These developments have resulted in the advent of engineering education, which has shaped the structure, content, and standards of engineering programmes worldwide. Furthermore, this progress laid the groundwork for the recognition of engineering as a regulated and accredited profession. Accreditation bodies, such as the Accreditation Board for Engineering and Technology (ABET) in the U.S[1], the Engineering Council in the UK[2], and Engineers Ireland[3] in Ireland, have emerged as custodians of engineering education, ensuring alignment between educational

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[1] https://www.abet.org/

[2] https://www.engc.org.uk/

[3] https://www.engineersireland.ie/Professionals

programmes and the needs of the profession via regularly updated accreditation criteria. Globally, other key accreditation bodies include institutions such as the Japan Accreditation Board for Engineering Education[4] (JABEE) and the Indian National Board of Accreditation[5] (NBA). Many of these bodies are, in turn members of the International Engineering Alliance (IEA), which establishes and enforces internationally benchmarked standards for engineering education and expected competences for engineering practice (Jurado *et al.*, 2005; Akera *et al.*, 2019).

By the early twentieth century, as the engineering profession grew in complexity, and the formalisation of engineering education began in universities, the need for standardisation became apparent (Kyne, 2021). Accreditation standards were established in the United States in 1908 when the American Society of Civil Engineers (ASCE) introduced the first engineering curriculum guidelines. This led to the creation of the Engineers' Council for Professional Development (ECPD) in 1932. These were later renamed ABET (Stephan, 2002). In Britain, the focus centred on professional examination systems managed by institutions such as ICE and IMechE rather than explicit accreditation of academic programmes. In Europe, the formal accreditation of engineering programmes began in France with a 1934 law that aimed to enhance both academic quality and job market relevance, setting a precedent for other European countries (Augusti, 2007).

During the post-war period (1940s–1970s), the formalisation and expansion of accreditation bodies underscored the critical importance of engineering in national development. This era witnessed increased investment in engineering education and training, with governments and professional bodies in Europe and the United States collaborating to align educational programmes with national priorities (Kyne, 2021). In the UK, the Engineering Council UK coordinated efforts between engineering institutions to set standards for professional qualifications.

Since the 1990s, global engineering accreditation bodies have further evolved, notably shifting from input-based to outcomes-based accreditation models. This transition emphasises the competencies and skills graduates acquire, rather than merely the educational content delivered (Gallery, 2021). ABET pioneered this shift by introducing the Engineering Criteria 2000 (EC2000). This framework moved the focus from prescriptive curricular requirements to assessing student learning outcomes, ensuring that graduates possess the necessary skills for professional practice. The implementation of EC2000 marked a paradigm shift in engineering education accreditation, promoting continuous improvement and accountability (Milligan, 2015).

Internationally, the Washington Accord[6], established in 1989, facilitated mutual recognition of engineering qualifications among signatory countries. Over time, it has encouraged the adoption of outcomes-based accreditation models globally, promoting consistency in engineering education standards and graduate competencies (Patil and Codner, 2007). In Europe,

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[4] https://jabee.org/en/

[5] https://www.nbaind.org/

[6] https://www.internationalengineeringalliance.org/accords/washington

the European Network for Accreditation of Engineering Education (ENAEE) developed the EUR-ACE framework[7], which sets standards for accreditation bodies based on learning outcomes. This framework ensures that graduates meet the professional competencies required across European higher education institutions, facilitating mobility and recognition of engineering qualifications.

The global trend toward outcomes-based accreditation reflects a commitment to producing engineers who are equipped with the necessary skills and competencies to meet the evolving demands of the profession. This approach aligns educational objectives with industry needs, ensuring that engineering graduates are prepared to address complex real-world challenges (Qadir *et al.*, 2020). A result of the outcomes-based approach adopted by accreditation bodies is a focus on the skills and competencies that graduates can demonstrate rather than solely on curricula (Crawley *et al.*, 2014). Furthermore, accreditation criteria have also evolved and now address global challenges such as climate change and societal well-being, reflecting the role of engineers in shaping sustainable futures (Byrne, 2023). For example, Engineers Canada introduced sustainability as a core graduate attribute in its 2021 Accreditation Criteria (Engineers Canada, 2021, p.8). Similarly, when it comes to digital transformation, accreditation bodies increasingly recognise the need to integrate digital technologies, such as AI and data analytics, into engineering education (ABET, 2023).

1.3.1 Accreditation in Ireland

Engineers Ireland is the approved national body for awarding professional titles and accreditation of programmes. It was originally known as the Institution of Civil Engineers of Ireland (ICEI) and has a rich history dating back to its establishment in 1835. As one of the oldest professional engineering organisations globally, it has evolved significantly to meet the changing needs of the profession, focusing on promoting engineering excellence, setting standards, and supporting professional development (Engineers Ireland, 2018). By the early twentieth century, the institution had begun encompassing other engineering disciplines, reflecting the diversification of engineering practices. It played a key role during Ireland's industrialisation, supporting large-scale infrastructure projects such as railways, bridges, and power plants (Kyne, 2021).

The institution officially rebranded as Engineers Ireland in 1969 to reflect its broader representation of engineering disciplines beyond civil engineering. At this time, it also introduced professional titles such as Chartered Engineer (CEng), signifying advanced professional competence. Furthermore, by becoming a signatory of the Washington Accord, it adopted international best practices in education and professional standards while also strengthening its role in accrediting engineering programmes in Ireland, ensuring that graduates meet international standards for mobility and competence.

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[7] https://www.enaee.eu/eur-ace-system/standards-and-guidelines/

When it comes to Engineers Ireland's function in the accreditation of engineering programmes, it plays a role in maintaining the quality and relevance of engineering education in Ireland. Its accreditation process ensures that engineering programmes meet rigorous academic and professional standards. Engineers Ireland accredits engineering programmes at various levels, for example, Honours Bachelor/Masters Degrees (National Framework of Qualifications NFQ Level 8/9), leading to the title of Chartered Engineer (CEng); Higher Certificate/Diploma (Level 6/7), leading to titles such as Associate Engineer (AEng) and Engineering Technician (EngTech). The accreditation criteria are aligned with the European Qualifications Framework[8] (EQF) and the relevant international accords. The accreditation process evaluates whether graduates achieve specific outcomes, known as graduate attributes and involves a detailed review of academic programmes by expert panels, and feedback is provided to ensure continuous improvement of engineering education. Accreditation by Engineers Ireland provides graduates with international recognition of their qualifications, enabling them to work globally without the need for additional assessments.

In response to modern challenges, Engineers Ireland updated its accreditation criteria in 2021 by engaging in a comprehensive stakeholder review process (Engineers Ireland, 2021). Included is a renewed focus on engineering management, sustainability, and a commitment to the ethical use of technology and data, along with an acknowledgement of the importance of health and safety, as well as equality, diversity, and inclusion (EDI) issues. As with previous versions of accreditation criteria, engineering programmes in Ireland must adapt in order to meet the updates.

1.4 Research focus and question

This study is situated at the intersection of engineering education, Industry 5.0, and professional accreditation. It adopts a social constructionist perspective, recognising that concepts such as "Industry 5.0" and "accreditation" are not fixed or universally agreed but are socially produced through discourse, institutional practices, and cultural context. Industry 5.0 is framed in this thesis as a contested and evolving construct shaped by policy narratives, organisational strategies, and educational practices and not just as a technological paradigm. Similarly, accreditation is treated as a regulatory mechanism that does more than assure quality: it constructs particular visions of what engineering education should be and, by extension, what kind of engineers should be produced.

From this perspective, accreditation criteria are understood as a site where social, industrial, and educational expectations are negotiated and codified. The Engineers Ireland Accreditation Criteria (2021) actively participate in constructing the meaning of engineering in the context of Industry 5.0 and therefore do not simply reflect external demands. This makes accreditation practices an important lens for examining how broader industrial paradigms are translated into

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[8] https://europass.europa.eu/en/europass-digital-tools/european-qualifications-framework

educational requirements and professional norms. This is the focus of this research study. Drawing on the research literature, a model of engineering education incorporating the core features of Industry 5.0 was developed (Engineering Education 5.0). Using this model as a lens, the research investigated how accreditation in engineering programmes at a Higher Education Institution in Ireland prepares students for Industry 5.0. The overarching research question guiding the study is:

> **Through the lens of Engineering Education 5.0, how does accreditation in engineering programmes at a Higher Education Institution in Ireland prepare students for Industry 5.0?**

Alongside the social constructionist orientation and the Engineering Education 5.0 model, this study is also guided by Ball's (1993) policy cycle framework. Ball conceptualises policy as a process that unfolds across three interrelated contexts: influence, text production, and practice and not as a fixed output. This framework is particularly relevant to accreditation, which functions simultaneously as a site of negotiation among stakeholders, a formalised set of criteria codified in policy texts, and a set of practices enacted within higher education institutions. By adopting Ball's framework, the study positions accreditation as a discursive and socially constructed process rather than a neutral mechanism of quality assurance. This framing aligns with the research question and provides the analytical lens through which the empirical phases are structured: examining accreditation board members' perspectives (context of influence), the 2021 Engineers Ireland Accreditation Criteria (context of text production), and institutional self-assessment reports (context of practice), leading to three sub-research questions:

- *Through the lens of Engineering Education 5.0, how do members of the accreditation board of Engineers Ireland understand the current accreditation criteria?*
- *How is Engineering Education 5.0 represented in the 2021 Engineers Ireland Accreditation Criteria?*
- *How is Engineering Education 5.0 represented in the programme outcomes in the self-assessment reports produced as part of accreditation in a HEI in Ireland?*

1.5 Researcher positionality

The positionality of the researcher is an important dimension of this study, as professional background, academic practice, and epistemological orientation shape how the research question has been framed and how the data are interpreted (Cohen, Manion and Morrison, 2017; Holmes, 2020). The researcher in this study has a dual career trajectory, combining professional practice as an engineer with an academic role as an engineering educator. With professional experience spanning telecommunications, medical devices, and project management since the early 1990s, and subsequent transition to academia in 2008, she occupies an insider position in relation to both industry and higher education. Recognition as a Chartered Engineer further reflects embeddedness within professional cultures where accreditation is regarded as both a marker of competence and a guarantor of professional identity (Denzin and Lincoln, 2011; Creswell and Creswell, 2018).

These lived experiences provided both motivation and sensitivity to the role of policy frameworks in shaping engineering education. As an educator engaged in curriculum design across undergraduate, postgraduate, and professional programmes, the researcher has observed how accreditation requirements influence the formal structure of programmes and also the everyday practices of teaching and learning. An interest in the historical development of engineering education, combined with awareness of external pressures such as industrial change, climate challenges, global disruptions, and, more recently, artificial intelligence, shaped the researcher's perspective. These factors fostered a desire to understand not only the content of accreditation criteria but also the processes through which they exert influence. This led to a deeper engagement with questions of how policies operate as social artefacts: how they frame values, codify expectations, and channel educational practices in ways that shape the construction of professional knowledge and identity.

This reflexive stance acknowledges that accreditation criteria are not neutral or static but are socially constructed through negotiation among professional bodies, industry, and educational institutions. The researcher's own position, situated at the intersection of practice and pedagogy, made it important to move beyond a positivist orientation traditionally associated with engineering, which prioritises technical objectivity, towards a social constructionist paradigm (Walther *et al.*, 2013). From this perspective, knowledge is viewed as relational and contingent, produced through discourse, institutional practices, and historical context. This orientation allows for an inquiry into how accreditation criteria actively participate in constructing the meaning of "Industry 5.0" within engineering education, rather than simply mirroring technological or industrial developments.

Accordingly, the study is informed by a social constructionist orientation that values meaning-making, contextual understanding, and reflexivity. Critical self-awareness underpins the research, providing a standpoint that recognises the influence of the researcher's professional trajectory while enabling a deeper exploration of how accreditation policies function as mechanisms of meaning-making and institutional power within engineering education.

While the researcher's dual identity as practitioner and educator provided valuable insight, it also introduced the potential for bias in framing the research questions, interpreting participant accounts, and privileging certain perspectives over others. Insider knowledge of accreditation processes and institutional practices may have influenced which issues foregrounded and the interpretation of findings. To mitigate this, the study engaged reflexively with positionality throughout the research process, drawing on established qualitative research protocols, critical reflection, and triangulation of data sources to guard against over-reliance on personal assumptions. Acknowledging this possibility of bias does not negate the results but rather strengthens their credibility by making transparent the interpretive lens through which the study was conducted.

1.6 Structure of the thesis

Chapter One provides an introductory outline of the study, including the background and context, as well as the rationale for pursuing research on Engineering Education 5.0. Chapter Two presents the literature review strategy and the findings of the review of the research Engineering Education 5.0 and professional accreditation relevant to this study. Chapter Three presents the methodological approach and research design. Chapter Four presents the results from the study with an in-depth discussion in Chapter Five. Finally, the contributions and limitations of the study, along with recommendations for future practice and research, are presented in Chapter 6.

Chapter 2: Literature review

2.1 Introduction

The genesis of this research came from a desire to explore and understand the influence of the latest industrial revolution on engineering education through the lens of professional accreditation. This literature review serves three key objectives. First, it seeks to identify, through existing research, the origins and influences of Industry 5.0 on engineering education within academic discourse. Second, it examines the role of professional accreditation in shaping engineering programmes and the development of contemporary engineers. Finally, it assesses the presence and influence of Industry 5.0 within Irish engineering education, analysing its integration through the framework of professional accreditation processes.

This review offers a critical appraisal of current literature, with a particular focus on research concerning the implications of Industry 5.0 for engineering education and accreditation. Adopting a state-of-the-art approach, it prioritises contemporary issues and emerging debates (Knopf, 2006). As Kennedy (2007) notes, such an approach "may offer fresh insights or highlight potential areas for future research" (p. 95). Although the review applies a rigorous methodological framework, it is not a systematic review in the strict sense outlined by Jesson (2011). Nevertheless, it is informed by the systematic principles set out by Cooper *et al.'s* (2018), including clearly defined inclusion and exclusion criteria, which are discussed in detail in subsequent sections.

This chapter is, therefore, structured to address the three objectives outlined above. It begins with an overview of the development of Industry 5.0 and its impact on engineering education, followed by a review of literature on the influence of accreditation bodies and the formulation of criteria on engineering programmes in Ireland. The final section is an intersection of the first two and examines the presence of Industry 5.0 on engineering education through the lens of professional standards for Irish engineering programmes, identifying gaps and ultimately leading to the study's overarching research question.

2.1.1 Terminology

Before detailing the search strategy and selection criteria for this literature review, a brief overview of terminology related to Industry 5.0 and other '5.0' topics in research is provided. Consistent with the social constructionist perspective of this research, terms with suffixes from 1.0 to 5.0 are deemed to be theoretical constructs. While these terms are useful for explanation, they are not tangible entities; thus, their interpretation within the literature review remains open to scrutiny and debate.

Research on Industry 5.0 is still emerging, leading to notable inconsistencies in terminology across scholarly work, which may cause ambiguity. Furthermore, scholars have increasingly adopted the '5.0' suffix across various sectors, including inter alia Government 5.0 (Kowalkiewicz and Dootson, 2019), Agriculture 5.0 (Balaska *et al.*, 2023), Manufacturing 5.0 (Kurniawan, Komara and Setiawan, 2019), Quality 5.0 (Arsovski 2019), Supply Chain 5.0 (Minculete, Bârsan and Olar, 2021; Villar, Paladini and Buckley, 2023), Education 5.0 (Kolade and Owoseni, 2022), and the focus of this study Engineering Education 5.0, first coined by (Lantada, 2020). The intention of scholars who adopt the '5.0' suffix is to create a shorthand linking their sector of interest to the overarching ideas around Industry 5.0.

Additionally, while the term Society 5.0 is sometimes used interchangeably with Industry 5.0, it has different origins and distinct meanings, as discussed in a later section. There is also literature examining Industry 5.0 through the lens of specific educational concepts such as 'lifelong learning' (Shanahan and Organ, 2022), 'upskilling' (Gürdür Broo, Kaynak and Sait, 2022), 'training' (Shahbakhsh, Emad and Cahoon, 2022), 'education' (Kopacek and Doyle-Kent, 2021) and 'engineering education' (Mitchell and Guile, 2021).

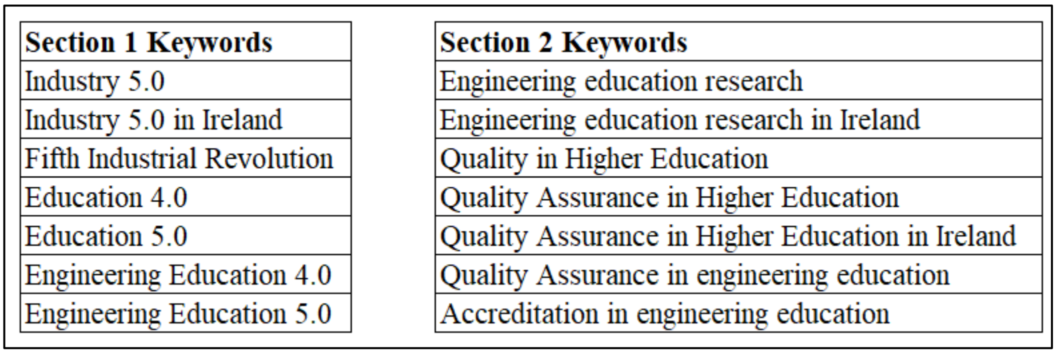
Therefore, for clarity, from the outset, this study adopts the definition of Industry 5.0 from the widely cited European Union Policy Brief (Breque, De Nul and Petridis, 2021, p.14) as presented in Chapter One.

2.1.2 Undertaking the literature review

The databases selected and accessed through DCU library resources for this review, Scopus, Engineering Village, Springer, and Google Scholar, were chosen to provide both breadth and depth across the scope of the study. Scopus provided access to a wide range of peer-reviewed journals, books, and conference proceedings across education, engineering, and policy, while Engineering Village ensured comprehensive coverage of engineering-specific scholarship, particularly around accreditation and professional practice. Springer was included for its extensive collection of books and edited volumes, which are central to debates on Industry 4.0, Industry 5.0, and engineering education. Finally, Google Scholar was used to capture grey literature, theses, and emerging publications not yet indexed elsewhere. Taken together, these databases provided complementary coverage and minimised the risk of omitting relevant studies.

The first part of the review focused on the emergence of Industry 5.0 using search terms such as 'Industry 5.0' and related educational and engineering terms, including 'Education 4.0', 'Engineering Education 4.0', 'Education 5.0', and 'Engineering Education 5.0'. The term 'Industry 5.0' began to gain traction in scholarly circles around 2019. Although publications prior to 2019 are limited, no specific start date was set for the search. The second part of the review centred on Quality Assurance (QA) in education and engineering education, accreditation, and related topics. The search for relevant literature used Boolean logic and truncation using the above search terms and is summarised in Table 2-1

Table 2-1: Initial search terms for literature review



Section 1 Keywords
Industry 5.0
Industry 5.0 in Ireland
Fifth Industrial Revolution
Education 4.0
Education 5.0
Engineering Education 4.0
Engineering Education 5.0

Section 2 Keywords
Engineering education research
Engineering education research in Ireland
Quality in Higher Education
Quality Assurance in Higher Education
Quality Assurance in Higher Education in Ireland
Quality Assurance in engineering education
Accreditation in engineering education

The studies included from the search terms were chosen according to the following overarching criteria:

- Relevance to the research aims - Each paper addresses at least one of the central concerns of this thesis: the evolution of industry paradigms (Industry 4.0 to 5.0), the implications for engineering education, the role of accreditation and quality assurance, or the socio-technical framing of these developments.
- Scholarly significance and representativeness - Seminal and widely cited works were included to capture the theoretical and policy foundations of the field. Alongside these, more recent contributions illustrate the emerging debates around Engineering Education 5.0 and its alignment with Industry 5.0.
- Diversity of source types - The table reflects a balance between peer-reviewed journal articles, books, conference proceedings, doctoral theses, and authoritative grey literature. This was necessary given that Industry 5.0 is an emergent paradigm, where policy documents and professional body outputs are shaping discourse alongside academic research.

The inclusion of works across multiple categories ensures that the review integrates conceptual, empirical, and policy perspectives. Accreditation literature was foregrounded because professional accreditation is the focal institutional mechanism examined in this study. The literature on Industry 4.0 and 5.0 provides the technological and socio-economic context in which engineering education reforms are situated. Engineering education research sources establish the scholarly discourse on teaching, learning, and professional formation. Finally, the socio-technical tradition was included to provide a theoretical anchor for understanding systemic change. These inclusion criteria resulted in a total of 1243 papers, as shown in Table 2-2.

Table 2-2: Initial results of literature searches from the databases

Database	Scopus	Engineering Village	Springer Link	Google Scholar	**Total**
Results	299	314	359	271	**1243**

2.1.3 Literature selection and filtering process

From this starting point, a series of systematic filters was applied:

- Duplication: - Repeated records retrieved across multiple databases were removed to avoid double-counting.
- Language filter: - Only works available in English were retained, to ensure comparability and avoid translation loss.
- Relevance filter (title/abstract screening): - Papers were excluded if their focus was overly technical (for instance, narrow AI or robotics design papers without educational or accreditation relevance) or if they addressed unrelated conference proceedings.
- Accessibility filter: - Where full texts were not accessible through institutional subscriptions or open access, these were set aside.
- Grey literature inclusion: - Authoritative grey sources, such as government reports, policy frameworks (for example, EU, QQI, Engineers Ireland, UNESCO), and professional body documents, were purposively added because of their role in shaping accreditation standards and engineering education practices.

This process reduced a very broad pool to a curated set of publications that are both manageable in scope and directly aligned with the aims of this study. The final corpus, summarised in Table 2-3, is therefore the product of systematic searching, purposive inclusion, and critical filtering. It offers both depth (seminal and empirical works central to accreditation and education reform) and breadth (capturing international, policy, and socio-technical perspectives) as shown in Table 2-4 and Table 2-5.

Table 2-3: Results of the literature search following filtering and search of grey literature

Flow of publication filter	**# of papers**
Records identified via databases (Scopus, Engineering Village, Springer, Google Scholar):	1243
Remove duplication	703
Language/inaccessible full text exclusions	439
Title/abstract screening exclusions (topic fit + remove highly-technical/no edu/QA link + non-relevant conferences)	278
Full-text exclusions (not meeting inclusion criteria)	156
Authoritative grey literature purposively added (EU/UNESCO/QQI/Engineers Ireland/ABET/ISO/OECD/Cabinet Office, etc.)	15
Final corpus included in qualitative synthesis	**171**

Table 2-4: Categories of literature for inclusion in the literature review

Category	# of papers
Industry 5.0 (general/context)	54
Education in Industry 4.0	12
Engineering Education 5.0 (development, curricula, competencies)	26
Accreditation (incl. standards, effects, CDIO/ABET/Engineers Ireland, policy-facing)	24
Quality assurance in higher education (QA/QE frameworks, ESG/EUA/OECD, ISO)	18
Engineering Education / EER (field overviews, methods, identities, design/pedagogy not specifically EE5.0)	27
Socio-technical foundations	6
Ethics-specific - where ethics is the primary focus, not subsumed under EE5.0	4
Total	**171**

Table 2-5: Number of papers in the literature review categorised by source type

Source type	# of papers
Peer-reviewed journal articles	95
Scholarly books/edited volumes & book chapters	22
Refereed conferences (ASEE/EDUCON/WEEF-GEDC/SEFI/IEEE/Frontiers, etc.)	35
Doctoral theses: 4 (e.g., Doyle-Kent 2021; Martin 2020; Gallery 2021; Homan 2020)	4
Authoritative grey literature/policy/standards: (e.g., ABET 1998; Engineers Ireland 2021; ESG 2015; EUA 2023; ISO 9000; QQI 2018/2022; UNESCO 2013; OECD 2022; Cabinet Office Society 5.0; EC I5.0 reports)	15
Total	**171**

Citations were imported into a referencing tool (Zotero), wherein directories were set up to manage the literature in a logical format.

2.2 Industry 5.0 development

Industry 5.0 addresses the limitations of Industry 4.0 by placing greater emphasis on the human element as both beneficiary and decision-maker (Simion, Avasilcai and Alexa, 2021). This section explores the emergence of Industry 5.0, delving into its theoretical framework, research trajectory, influences, and educational impact. At its essence, the construct of Industry 5.0 retains and supplements Industry 4.0 technologies while expanding the role of industry in society (Skobelev and Borovik, 2017; Gürdür Broo, Kaynak and Sait, 2022; Leng *et al.*, 2022). Key factors driving the transition include United Nations Sustainable Development Goals (UNSDGs), customisation, trust, privacy, and data security (Enang, Bashiri and Jarvis,2023), alongside socio-cultural and environmental issues like an ageing population, energy efficiency, climate change, and the COVID-19 pandemic.

2.2.1 Theoretical framework of Industry 5.0

The theoretical framework of Industry 5.0 is rooted in socio-technical theory (Breque, De Nul and Petridis, 2021), which emphasises the co-optimisation of social and technical systems to achieve both organisational efficiency and human well-being (Trist, 1981; Mumford, 2006). By extending the techno-economic approach of Industry 4.0, Industry 5.0 adopts a more holistic idea of sustainability, human-centricity, and resilience, aligning with the principles of socio-technical systems thinking (Cummings, 1978; Bijker, 1997; Geels, 2004; Prassida and Asfari, 2022).

Barata and Kayser (2023) position Industry 5.0 as a socio-technical evolution where social and technical dimensions merge seamlessly. Drawing on the work of Breque, De Nul and Petridis (2021), they highlight how Industry 5.0's pillars reflect a renewed emphasis on the social value of manufacturing by foregrounding the importance of human knowledge and skills. This perspective frames Industry 5.0 not merely as a manufacturing revolution but as a transformative societal force that reshapes how humans interact with technology. Fair and Modafferi (2022) further articulate the ideals of Industry 5.0, including prosperity, resilience, sustainability, inclusivity, equality, and well-being, as deeply embedded in socio-technical theory. They illustrate how humans and robots collaborate, sharing roles and agency, which epitomises the harmonious integration of social and technical systems. Similarly, Pascarella and Bednar (2021) perceive Industry 5.0 as advancing systemic sustainability by balancing technological progress with societal needs. The EU's conceptualisation of Industry 5.0, as described in its 2021 policy (Breque, De Nul and Petridis, 2021), uses the metaphor of a three-legged stool to represent its core pillars: sustainability, resilience, and human-centricity. These equally important, interconnected elements are deemed essential for achieving the broader goals of Industry 5.0 and ensuring its successful implementation. This framework, illustrated in Figure 2-1, underscores how Industry 5.0 moves beyond traditional manufacturing paradigms to embrace a socio-technical vision that prioritises the integration of human values with technological advancements.

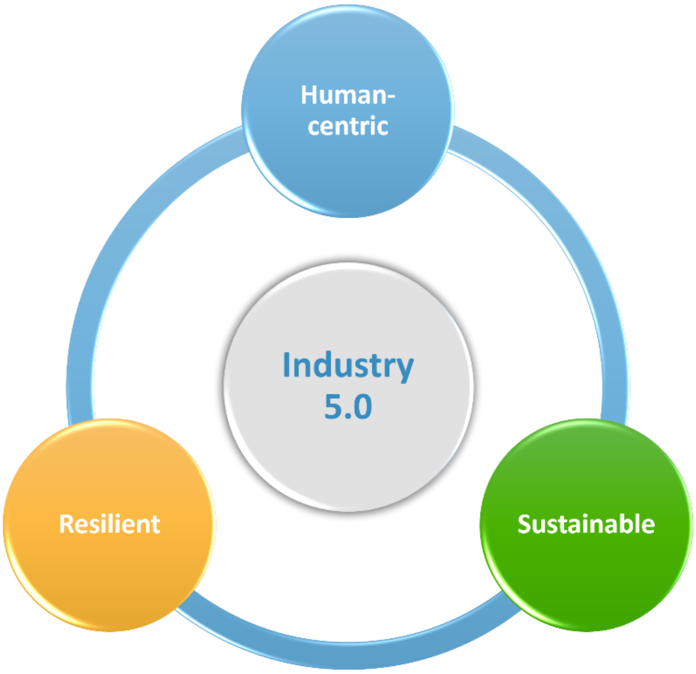


Figure 2-1: EU conceptualisation of Industry 5.0, as described by Breque, De Nul and Petridis (2021)

At the heart of Industry 5.0 is the prioritisation of human well-being, positioning workers not as cost factors but as essential contributors to industrial and societal success. This principle reflects the socio-technical emphasis on designing systems that empower individuals and enhance collaboration between humans and machines (Cherns, 1976) For example, Breque, De Nul and Petridis (2021) highlight initiatives such as Operator 4.0, which integrates technologies like augmented reality and collaborative robots to enhance, rather than replace, human capabilities. Such approaches align the focus of socio-technical theory on fostering user-centric systems that adapt to human needs, ensuring both productivity and user satisfaction. The integration and convergence of human and AI in smart factories can foster personal development and responsibility for workers (Demir, Döven and Sezen, 2019; Doyle-Kent and Kopacek, 2020; Bhandurge and Bhide, 2021; Xu *et al.*, 2021; Campagna and Rehm, 2023).

Industry 5.0 also extends its remit to include environmental sustainability, advocating for circular processes that reduce waste, optimise resource efficiency, and operate within planetary boundaries. This aligns with socio-technical theory's systemic perspective, which views organisations as embedded within larger environmental and societal contexts. The use of advanced technologies, such as AI and additive manufacturing, to achieve these goals mirrors the socio-technical principle of integrating technical innovations with societal imperatives to ensure holistic optimisation (Leonardi, 2011). Industry 5.0 promotes respecting planetary boundaries through circular processes that reuse, repurpose, and recycle resources, thereby reducing waste and environmental impact. This includes minimising energy use and emissions to prevent resource depletion (Breque, De Nul and Petridis, 2021; Zengin *et al.*, 2021; Dwivedi and Sharma, 2022;

Ghobakhloo *et al.*, 2022; Grabowska, Saniuk and Gajdzik, 2022; Souza, Ferenhof and Forcellini, 2022).

Industry 5.0 further emphasises building resilience into industrial systems to withstand disruptions such as global supply chain shocks or environmental crises. Geopolitical shifts and crises, such as the COVID-19 pandemic, underscore the fragility of global production. Resilience in Industry 5.0 is achieved through strategic value chains, adaptable production, and flexible processes, ensuring systems can withstand major disruptions and support critical infrastructure (Javaid and Haleem, 2020; European Commission, Directorate-General for Research and Innovation, 2021; Rachmawati *et al.*, 2021; Xu *et al.*, 2021; Jefroy, Azarian and Yu, 2022; Zizic *et al.*, 2022; Leelavathi *et al.*, 2023). Resilience encompasses both self-sufficiency and system strength, making production robust against crises. This approach reflects socio-technical theory's recognition of the dynamic and adaptive nature of systems, which must balance technical efficiency with the flexibility required to respond to external challenges (Trist, 1981). For instance, Industry 5.0 promotes modular production systems, real-time risk monitoring, and flexible value chains to enhance industrial robustness (Ghobakhloo *et al.*, 2022). These are key socio-technical attributes that address both human and technical vulnerabilities.

Another distinguishing feature of Industry 5.0 is its commitment to worker empowerment through participatory design processes (Breque, De Nul and Petridis, 2021). Workers are actively involved in shaping and deploying new technologies, ensuring their roles evolve alongside automation rather than being replaced by it. This participatory approach resonates with socio-technical theory's emphasis on involving stakeholders in system design to achieve joint optimisation of social and technical components (Mumford, 2006). Projects such as Factory2Fit, (Breque, De Nul and Petridis, 2021, p.15) which leverage worker feedback and co-design to improve industrial processes, exemplify this principle.

Industry 5.0 also adopts a systemic approach that integrates social, environmental, and technical dimensions into a cohesive framework. This reflects a socio-technical view of organisations as interdependent systems that require alignment between human and technical elements for long-term success (Trist, 1981). The EU policy brief's emphasis on stakeholder value, as opposed to purely shareholder value, further underscores its socio-technical orientation by embedding social priorities into technological innovation.

In summary, Industry 5.0 operationalises socio-technical theory by prioritising human-centricity, sustainability, and resilience within industrial systems. It moves the purpose of industry beyond profit maximisation to address societal and environmental challenges. By integrating human and technical systems, Industry 5.0 aims to ensure that technological advancements are equitable, inclusive, and responsive to societal needs, embodying the core tenets of socio-technical systems thinking (Mumford, 2006; Fair and Modafferi, 2022). As such, it represents an evolution of industrial paradigms, grounded in the principles of socio-technical theory to foster a sustainable and human-centered future.

2.2.2 Trajectory of Industry 5.0 research

A meta-analysis carried out by Barata and Kayser (2023) contextualises Industry 5.0's origins, and the emerging research landscape by identifying:

- **2017-2019:** Initial divergence of Industry 5.0 from Industry 4.0.
- **2020-2021:** Focus on societal priorities for digital transformation.
- **Since 2022:** Exploration of synergies between technological advances and improved human-centred futures.

This trajectory reveals a shift from purely technological concerns toward an integrated socio-technical vision. From a skills perspective, however, Barata and Kayser (2023) note that research remains limited. They identify only two key studies addressing this dimension: Broo, Kaynak and Sait (2022), who explore the future skills needed for engineering education in the context of Industry 5.0, and Carayannis *et al*. (2022), who argue that digitalisation creates new opportunities for higher education to become a catalyst for transformation.

Beyond the education sector, Madsen and Berg (2021) observe a growing body of Industry 5.0 scholarship, particularly in Germany, where early adoption was cautious due to the country's entrenched commitment to Industry 4.0 (Hein-Pensel *et al.*, 2023). Expanding on this, Villar, Paladini and Buckley (2023) use network analysis to demonstrate how Industry 5.0 can complement the profit-driven, competitive nature of Industry 4.0, enabling organisations to maintain resilience in the face of disruption. Similarly, Akundi *et al,* (2022) identify several emerging research themes within Industry 5.0, including supply chain optimisation, enterprise innovation and digitalisation, smart and sustainable manufacturing, and advanced human-machine collaboration.

Taken together, these studies indicate a growing scholarly interest in the potential of Industry 5.0 to support more collaborative and resilient forms of industrial practice. However, despite this increasing attention, the educational dimension, particularly in relation to engineering education, remains underexplored. To better understand this gap, the following section examines the origins and key influences shaping the Industry 5.0 concept.

2.2.3 The origins of Industry 5.0

Research on the topic of Industry 5.0 reveals diverse interpretations across disciplines. Özdemir and Hekim (2018) view it as an extension of Industry 4.0, questioning the need for a new term. In contrast, Skobelev and Borovik (2017) conceptualise it as a fusion of AI and human life, prioritising human well-being for harmonious coexistence with technology. Nahavandi (2019) and Doyle-Kent (2021) support this human-centric vision, describing Industry 5.0 as a partnership where humans and machines enhance one another. Similarly, Leong *et al*. (2021) predict greater integration between AI-driven systems and human interaction.

Akundi *et al*. (2022) highlight Industry 5.0's emphasis on sustainability, recognising planetary limits and supporting workers. Banholzer (2022) stresses its potential for addressing societal challenges through transparency and interdisciplinary innovation, while Habash (2022) underlines its democratising potential, framing Industry 5.0 as a human-centred transformation led by technology. Yet, definitional clarity remains elusive. To this end, Longo, Padovano and Umbrello (2020) characterise it as an era of human-machine augmentation, but note ongoing ambiguities.

From 2021, research on Industry 5.0 has marked a shift towards integrating AI and other emerging technologies with human collaboration. While some scholars see it as a natural evolution from Industry 4.0, others focus on its human-centric and sustainable principles. The EU's 2021 policy brief defines Industry 5.0 as prioritising planetary boundaries and worker well-being (Breque, De Nul and Petridis, 2021). However, despite its promise of sustainable, human-centred progress, academic perspectives highlight both its potential and the uncertainties surrounding its definition and shared understanding.

2.2.4 Wider influences on Industry 5.0 development

Industry 5.0 emerged to address the limitations of Industry 4.0, influenced by global policies and societal goals, particularly the UNSDGs, which promote a human-centric, resilient, and sustainable approach (Kasinathan *et al.*, 2022; Leng *et al.*, 2022; Zeb *et al.*, 2022). Key SDGs, such as SDG 4 (quality education), SDG 9 (sustainable industry), and SDG 12 (resilient infrastructure and innovation), underpin its principles. For instance, Ghobakhloo *et al*. (2022) outlines sixteen essential functions for sustainability in Industry 5.0, including intelligent automation and renewable resource integration, highlighting its dual focus on technological advancement and ecological responsibility.

At the European level, the emergence of Industry 5.0 has been influenced by initiatives such as the EU Green Deal[9] and the EU Digital Agenda[10] advocate for a circular economy and sustainable resource use, lessons reinforced by the COVID-19 pandemic (Xu *et al.*, 2021). The European Pillar of Social Rights[11] further aligns with Industry 5.0 by supporting fair working conditions and shifting from profit-driven goals to human-centric, socio-environmental sustainability (Alexa, Pîslaru and Avasilcai, 2021; European Commission, Directorate-General for Research and Innovation, 2021).

Society 5.0, introduced by the Japanese government, seeks to create a "super-smart" society that balances economic growth with social and environmental well-being, particularly addressing challenges such as an ageing population. It builds on earlier societal stages: hunter-gatherer (Society 1.0), agricultural (Society 2.0), industrial (Society 3.0), and information (Society 4.0) (Cabinet

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[9] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[10] https://www.europarl.europa.eu/factsheets/en/sheet/64/digital-agenda-for-europe

[11] https://employment-social-affairs.ec.europa.eu/policies-and-activities/european-pillar-social-rights-building-fairer-and-more-inclusive-european-union_en

Office, 2017; Huang *et al.*, 2022). While often conflated with Industry 5.0, the two differ in focus. Society 5.0 prioritises integrating advanced technologies for societal benefit, such as in healthcare, aligning closely with the SDGs (Narvaez Rojas *et al*., 2021; Banholzer, 2022). In contrast, Industry 5.0 aims to address the challenges of industrialisation through human-centric, sustainable practices. Although both concepts reflect a shared timeline, they address distinct aspects of technological and societal transformation. Figure 2-2 presents both concepts within their historical context. It demonstrates the Japanese model of human society transformations and the western Industrial revolutions, which took place in a much shorter timeframe.

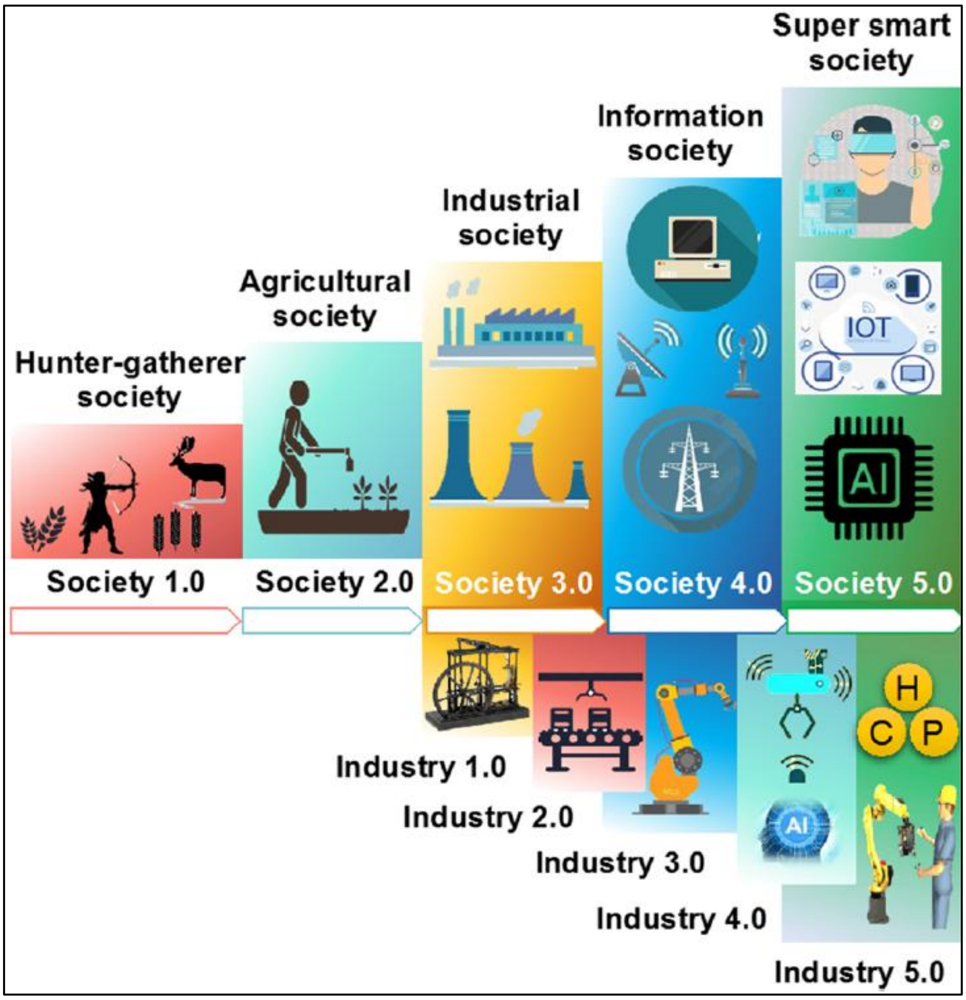

Figure 2-2: Japanese model of human society transformations and the western industry evolution (Huang *et al.*, 2022)

In Ireland, Industry 5.0 research has focused mainly on manufacturing. Doyle-Kent (2021) explored the role of collaborative robots (Cobots) in task expansion, while Doyle-Kent and Kopacek (2021, 2022) proposed an Industry 5.0 framework emphasising specialised training for Cobots. Irish government policies further support Industry 5.0 initiatives, prioritising sustainability to meet national climate goals (DBEI, 2019; Enterprise Ireland, 2019; IDA Ireland, 2022).

2.3 Engineering education before Industry 5.0

Chapter One provided an overview of the industrial revolutions (Industry 1.0-4.0) and offered context for the emergence of the new paradigm of Industry 5.0. This section considers the landscape of education in the era of Industry 4.0 before zoning in on engineering education associated with Industry 4.0 (also referred to as Engineering Education 4.0 in the literature). It outlines the challenges and paves the way for a discussion on the development of the vision of engineering education in the era of Industry 5.0.

2.3.1 Education in the era of Industry 4.0

Rajkumar *et al*. (2010) identified key technical challenges in cyber-physical systems during the early days of Industry 4.0, emphasising the need for collaboration between researchers and educators. However, businesses struggled to implement Industry 4.0 due to a significant skills gap between graduates and the workforce (Bongomin *et al.*, 2020). This highlighted the critical role of higher education in driving societal and cultural shifts necessary for Industry 4.0 adoption.

In response, Education 4.0 models emerged, integrating technology and human capabilities to unlock new possibilities (Hussin, 2018). Salmon (2019) urged academic institutions to embrace risk and enhance their adaptability in this new era, advocating for changes in curricula and learning models to achieve what she describes as “long-lasting constructive transformation” (p. 15). Similarly, Fisk (2017) identified nine key trends shaping Education 4.0, including the growing importance of learners independently identifying knowledge sources and acquiring new, future-oriented skills (Table 2-6).

Table 2-6: Nine key trends related to Education 4.0 (adapted from Fisk (2017))

1	Learning can take place anytime, anywhere
2	Learning will be personalised
3	Students have choice in how they want to learn
4	More project-based learning
5	More hands-on learning through field experience such as internships mentoring projects and collaborative projects
6	More data interpretation in which they are required to apply their theoretical knowledge
7	Students will be assessed differently and the conventional platforms to assess students may become irrelevant or insufficient
8	Students opinion will be considered in designing and updating the curriculum
9	Students will become more independent in their own learning

Building on these perspectives, Gavhane (2020) argues that higher education must go beyond institutional transformation to actively bridge cultural and societal gaps, enabling learners to become more globally aware, socially responsible, and adaptable to rapid change.

In summary, Education 4.0 signified a shift from traditional models to technology-driven approaches, integrating virtual and interactive face-to-face components through blended learning. Virtual courses included features such as personalisation, gamification, adaptability, learning analytics, intelligent virtual tutors, communities of practice, and e-assessment (Ciolacu *et al.*, 2019, 2020). This approach aligns with Industry 4.0 by promoting key competencies such as problem-solving, adaptability, and technological proficiency. Chakraborty *et al.* (2023) emphasised that Education 4.0 leveraged advanced information and communication technologies (ICT) to meet Industry 4.0's demands. Despite its promise, implementing Education 4.0 faced significant challenges, mirroring those of Industry 4.0 (Sivasankaran and Karthikeyan, 2021).

2.3.2 Engineering education in the era of Industry 4.0

Each technological leap has necessitated educational shifts to prepare engineers for emerging challenges, accompanied by the development of relevant concepts and frameworks (Lantada, 2020). For instance, the Conceive-Design-Implement-Operate (CDIO) framework seeks to develop engineers capable of managing complex value-added engineering systems. (Jørgensen, 2006; Crawley *et al.*, 2014; Martínez-Araned *et al.*, 2022). It emphasises a curriculum that integrates these four stages, promoting hands-on learning and real-world system development. The curriculum was developed with input from industry and academia to ensure that graduates possess the necessary skills for modern engineering challenges. Another example is the concept of the 'global engineer', which emphasises the need for engineers to possess competencies that enable them to operate effectively in an interconnected and multicultural world. This model of engineering education integrates technical expertise with skills such as cultural awareness, international collaboration, and adaptability to diverse environments (Amadei, 2018).

The rise of Industry 4.0, marked by smart technologies and digitalisation, spurred the emergence of Engineering Education 4.0. Ramirez-Mendoza *et al.*, (2018) proposed a curriculum integrating interdisciplinary knowledge, advanced technological skills, and industry practices, emphasising adaptability and innovation. Moreover and based on the ELLI project, the *Engineering Education 4.0: Excellent Teaching and Learning in Engineering Sciences* (Frerich *et al.*, 2016) highlighted innovations to align teaching with Industry 4.0. It addressed themes such as virtual learning environments, mobility, and professional competencies, although gaps remain in addressing social and policy implications of Industry 4.0.

In Ireland, Engineers Ireland (2020) reported that 91% of engineering employers experience skills shortages, encompassing both technical and transversal competencies such as organisational skills. This finding underscores the need for educational reform. In response, the Rethinking Engineering Education in Ireland (REEdI) project[12], led by Munster Technological

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[12] https://reedi.ie/

University, integrates immersive technologies and industry collaborations to equip students with workplace-ready competencies. This initiative aligns with Engineering Education 4.0, which prioritises curriculum adaptation to Industry 4.0 requirements, with a strong emphasis on digitalisation and academic-industry partnerships (Boyle *et al.*, 2022). This approach reflects the increasing pressures on educational institutions to update curricula and pedagogical strategies in response to rapid technological advancements, necessitating sustained investment in professional development for both staff and students (Lawrence, Ching and Abdullah, 2019). Examples of other Industry 4.0 modules or programmes in Ireland include *Industry 4.0* (ATU, 2023), *Industry 4.0 and Industrial Internet of Things* (MTU, 2023), *Advanced Manufacturing in Industry 4.0* (DCU, 2023), and *Introduction to Manufacturing Simulation and Robotics* (UCD, 2023).

Globally, engineering education faces similar challenges. For instance, in the US, Das, Kleinke and Pistrui (2020) identified barriers to adopting Engineering Education 4.0, (see Table 2-7), which underscores the importance of aligning education with evolving industrial demands.

Table 2-7: Challenges implementing Engineering Education 4.0 (adapted from Das, Kleinke and Pistrui (2020))

1	Lack of staff with industry 4.0 skills to fill curriculum requirements
2	Existing curricula is already congested, filing accreditation requirements, adding new material requires deletion of some existing content
3	Traditional credit hour, semester based course delivery may not facilitate rapid inclusion of industry 4.0 specific content
4	Rapidly changing technology has become the norm, but academica is not agile
5	The cost of equipment and facilities is prohibitive, especially rapidly changing technology that is virtually disposable
6	The staff promotion and tenure system is not designed to promote curricular experimentation
7	The difficulty of scaling up from a successful effort with a small group of students to a large student body
8	University system favours and rewards research and is designed to train students for graduate schools and research which overshadows the work to develop quantities of industry 4.0 skilled workers who will work in industry after an undergraduate degree
9	University research is often given priority over workforce preparation

Therefore, skills shortages, rapid technological change, and resource limitations highlight the need for a revised approach to fully harness modern engineering education and align with the ideals of Industry 5.0.

2.4 Towards Engineering Education 5.0

The transition from Engineering Education 4.0 to 5.0 parallels the evolution from Industry 4.0 to Industry 5.0. Research to date on Engineering Education 5.0 (also referred to in the literature as Industry 5.0 in engineering education) advocates integrating advanced technologies while simultaneously addressing societal and environmental challenges, aiming to equip engineers with the skills necessary to navigate complexity, foster human-machine collaboration, and engage with global challenges. Industry 5.0's principles, emphasising personal data ownership, sustainability, transparency, and resilience, are reshaping higher education. Seeling, Roberts and Weible (2022) support this shift by proposing educational frameworks that prioritise these values, while Andres *et al.* (2022) highlight the role of interdisciplinary curricula in fostering resilience. These perspectives reinforce the transformative impact of Industry 5.0 on higher education.

The relationship between Industry 5.0 and Engineering Education 5.0 is inherently symbiotic. On the one hand, Industry 5.0 drives education by informing the competencies and values prioritised in Engineering Education 5.0. For example, as industries shift focus toward sustainability, resilience, and human-centricity, engineering programmes are increasingly embedding these principles into their learning outcomes and pedagogical approaches. On the other hand, Engineering Education 5.0 plays a critical role in shaping industry by producing a workforce capable of realising Industry 5.0's humanistic and operational ambitions, thereby contributing to broader societal transformation. As Lantada (2020) argues, it must transcend technological training to embrace ethics, humanism, and social responsibility, preparing engineers to lead in complex socio-technical environments and to uphold the values central to Industry 5.0.

At a policy level, the European Commission, in its seminal publication, emphasises the importance of aligning education with Industry 5.0 through digital transformation, AI integration, and stronger academia-industry collaboration (Breque, De Nul and Petridis, 2021). Similarly, Tavares, Azevedo and Marques (2022) highlight the potential of Industry 5.0 to advance inclusive education and promote societal sustainability. Therefore, with the emergence of Industry 5.0, a growing body of literature advocates for the need to rethink engineering education to prepare engineers for modern complexities, emphasising ethics, sustainability, and global challenges. For instance, Lantada (2020) envisions Engineering Education 5.0 as a dynamic, modular model prioritising personalised learning, collaborative approaches, lifelong learning, and the integration of technical knowledge with social considerations. Broo, Kaynak and Sait (2022) stress the importance of lifelong learning and transdisciplinary approaches, proposing curricula that include sustainability, resilience, human-centric design, data management, and human-machine interaction. These ideas align with Lantada's call for transformative engineering education, addressing the demands of Industry 5.0 through adaptability and emerging skill sets. Ghani (2022) extends this by demonstrating the need for project-based learning to incorporate technology, sustainability, and ethics, leveraging open-source resources and AI to ensure equitable and practical education.

A major challenge for universities lies in equipping students with digital competence and ethical awareness. Ethics training is crucial to prepare engineers for the risks and responsibilities of advanced technologies (Kopacek and Doyle-Kent, 2021; Al-Emran and Al-Sharafi, 2022). Jiménez López *et al.* (2022) and Bigan (2022) advocate for integrating AI and enabling technologies into programmes, while Cuckov *et al.* (2022) recommend programme reforms to align with Industry 5.0 principles. This emphasis on ethical responsibility and technological fluency forms a natural bridge to the Engineering Education 5.0 paradigm. Lantada (2020) describes Engineering Education 5.0 as transcending technology to emphasise ethics and humanism, equipping engineers to lead in socio-technical environments, address technological singularity, uphold human rights, and foster a sustainable and equitable global society. This outlook highlights ethics, human-centricity, and the challenges of rapid technological advancement as central to this new paradigm.

Overall, the literature consistently advocates for adaptive, interdisciplinary education focused on societal and environmental impacts. While agreement exists on many principles, less clarity surrounds their practical integration into programmes. Building on this scholarly foundation, the following section presents an updated model of Engineering Education 5.0 developed as a framework for this study.

2.4.1 Developing an Engineering Education 5.0 model

To support the design implementation of this study, a conceptual model of Engineering Education 5.0 was developed to address the evolving demands placed on engineering graduates in the context of Industry 5.0. Existing literature revealed a need for a forward-looking framework that moves beyond traditional technical competencies to embrace interdisciplinarity, adaptability, and a strong orientation towards societal and environmental responsibility. Through a review and synthesis of key academic sources, seven defining features of Engineering Education 5.0 were identified: technical competency, sustainability, ethics and social impact, collaboration, educational approaches, global and cultural perspectives, and holistic and human-centric.

To develop the model, a reflexive thematic analysis approach (RTA), informed by Braun and Clarke (2006, 2019) was adopted. It is a method explicitly compatible with a social constructionist, interpretivist stance: It assumes that themes do not simply emerge from data but are actively generated through the researcher's theoretically informed engagement with the material. This aligns with the aim of this study to develop an interpretive model of Engineering Education 5.0, where the goal is to construct a coherent framework from evolving accounts in the literature.

Using Braun and Clarke's (2006, 2019) process also provided a systematic, transparent structure for the analysis, from familiarisation and initial coding through to theme development, review and definition. Its use was believed to strengthen the trustworthiness and auditability of the model-building process. The stages, which are outlined in more detail in the following sections, include: familiarisation with the literature, generating initial codes, searching for themes, reviewing themes, and defining and naming themes

2.4.1.1 Phase 1: Familiarisation with the Literature

From the total corpus of 171 papers, identified through the search of the literature, as described in section 2.1.3, 21 papers were found to focus on the emerging discourse at the intersection of Industry 5.0 and engineering education. These papers listed in Appendix A met three broad inclusion criteria: topical relevance, conceptual and/or practical contribution, and recency and disciplinary fit. Papers relating to topical relevance, address Industry 5.0, Education 5.0 or

Engineering Education 5.0, and discussed implications for engineering curricula, competencies, or pedagogies (for instance, Lantada 2020; Ghani 2022; Tavares et al. 2022; Andres et al. 2022). Papers addressing conceptual and/or practical contributions focused on conceptual framings (for example, paradigm descriptions, mappings between Industry 5.0 and Education 5.0), competency frameworks, and practice-oriented studies on curriculum design, XR, collaborative robots, project-based learning, micro-credentials, EDI or transversal skills. This breadth ensured that the eventual Engineering Education 5.0 model would be grounded in both high-level theory and concrete educational practice. Finally, papers published between 2020 and 2023 were selected because this window captures the most recent discourse and aligns with the practical timeframe of the review itself. 2020 marks the start point for the review (as justified in Section 2.1.2), reflecting the point at which relevant debates and re-framings accelerated. 2023 was used as the endpoint because it corresponds to when the literature review was conducted, providing a clear and transparent cut-off. This delimitation ensured the review reflected contemporaneous thinking on how engineering education is being re-imagined in response to Industry 5.0.

Following further screening, this set of 21 papers was reduced to eight papers. This was conducted as follows: The first step involved refining the dataset to include only papers that focus substantively on engineering education:

- Research whose primary focus was general higher education, workforce skills, or broad societal change, rather than engineering education specifically, were excluded.
- Studies that mentioned Industry 5.0 but did not develop concrete curricular, pedagogical or assessment implications for engineering were also excluded.

This reduced the set of papers to 14, each of which substantively addressed engineering programmes, engineering students, or engineering-specific curriculum/competency design. The second step prioritised papers that offered deeper a conceptual and empirical treatment of Engineering Education 5.0 features. Papers were included if they:

- Explicitly framed engineering education in relation to Industry/Education/Engineering Education 5.0, rather than treating the concept only as a backdrop.
- Offered rich conceptualisation or detailed empirical insight into features directly relevant to a model of Engineering Education 5.0 (for instance, human-centricity, sustainability, digital–human collaboration, project-based learning, critical thinking, XR and collaborative robotics in learning).

This led to a final set of eight papers (see Table 2-8) that were used to develop the model of Engineering 5.0. Collectively, they articulate paradigm-level shifts, detail concrete curricular and pedagogical innovations, and specify the capabilities and value orientations expected of future engineers. This smaller, theoretically and empirically rich subset provided the primary analytic basis for deriving and refining the features of the Engineering Education 5.0 framework.

Table 2-8: Set of papers used for model development

Authors	Paper title
Cuckov *et al.* 2022	Engineering reimagined: (Re)designing next-generation engineering curricula for Industry 5.0,
Forcael, Garcés and Lantada 2023	Convergence of Educational Paradigms into Engineering Education 5.0
Ghani 2022	Engineering education at the age of Industry 5.0 - higher education at the crossroads
Gürdür Broo, Kaynak and Sait 2022	Rethinking engineering education at the age of Industry 5.0
Lantada, 2020	Engineering Education 5.0: Continuously evolving engineering education
Mendonça, Pinto and Babo, 2020	Industry 5.0 expectations of engineering critical thinking,
Mourtzis, Angelopoulos and Panopoulos 2023	Extended reality (XR) applications for engineering education 5.0
Vogel, Lindner and Kratzsch 2023	Practical Engineering Education: Use of collaborative robots in the context of Industry 5.0

Also, during this phase, as advocated by Braun and Clarke (2006, 2019), crafting analytic memos helped shape early thinking and were maintained to document initial impressions, contradictions, and emerging constructs. For example, while reading Lantada (2020), a tension was noted between the drive for technological advancement and the ethical imperative to resist techno-solutionism. A memo recorded:

> *Are we teaching engineers to shape society or simply to serve the latest tech agenda? Engineering Education 5.0 must resist equating innovation with progress unless grounded in human values*

This shaped early thinking about the 'Ethics and Social Impact'. Other memos related to:

- Ambiguity around human-centricity: Gürdür Broo, Kaynak, and Sait (2022) repeatedly reference human-centric design, but the term appeared under-theorised across the literature. Memo: *What does human-centricity look like in practice: who defines the human? Whose well-being is prioritised*?
- Emerging collaboration: Early reading of Forcael, Garcés and Lantada (2023) highlighted recurring references to student-industry partnerships and interdisciplinary teamwork. Memo: *Collaboration is being positioned as both a learning method and a societal value; should this be treated as pedagogy, competence, or graduate attribute?*

2.4.1.2 Phase 2: Generating Initial Codes

Initial codes were developed inductively across the eight papers. Codes such as "lifelong learning," "sustainability integration," "global responsibility," and "ethical foresight" were identified recurrently. Overall, 143 codes were identified. These codes captured two related aspects of the literature. They reflected explicit recommendations about what engineering education should include or prioritise, such as embedding sustainability or strengthening lifelong learning. These represent the value-based assumptions about what engineers ought to do and what kind of professionals they should become. For example, Lantada (2020) explicitly highlights the need for engineers to safeguard human rights and promote global equity; even when not directly labelled as such, his account clearly conveys a normative commitment to justice in how future engineers should act.

2.4.1.3 Phase 3: Searching for Themes

Following initial coding, related codes were grouped into broader candidate themes that could serve as the conceptual foundation of the Engineering Education 5.0 model. This was not a purely mechanical sorting task; rather, it required interpretive judgment, underpinned by the central aim of establishing features of Engineering Education 5.0 that align with Industry 5.0 principles.

Analytic memos and coding notes were revisited to cluster codes that appeared to speak to shared conceptual domains. For example, "lifelong learning," "curriculum adaptability," and "self-directed learning" were provisionally grouped under Educational Approach. References to "data governance" and "societal impact of engineering" were grouped under Ethics and Social Impact. Similarly, codes related to "engaging students", strengthening partnerships" and "collaborative learning" grouped under Collaboration

Several alternative thematic configurations (typically five to ten candidate themes at a time) were then explored using visual mapping. This step was used to test whether candidate themes were internally coherent, i.e. if the codes within them genuinely belonged together, and if they were externally distinctive, and not simply duplicating neighbouring themes. Mapping also helped identify overlaps, gaps, and hierarchy. This found that some themes functioned better as sub-themes or as cross-cutting features. One illustrative configuration is presented in Figure 2-3 where items are positioned on adjacent branches to signal conceptual proximity. For example, Data Fluency with Personalisation in Education and Flexible Learning represent codes that were interpreted as closely connected. The figure captures how early theme boundaries were explored and tested. It is not intended to represent the final thematic structure, but rather a tool for comparing alternative groupings before moving to Phase 4 (reviewing and refining themes).

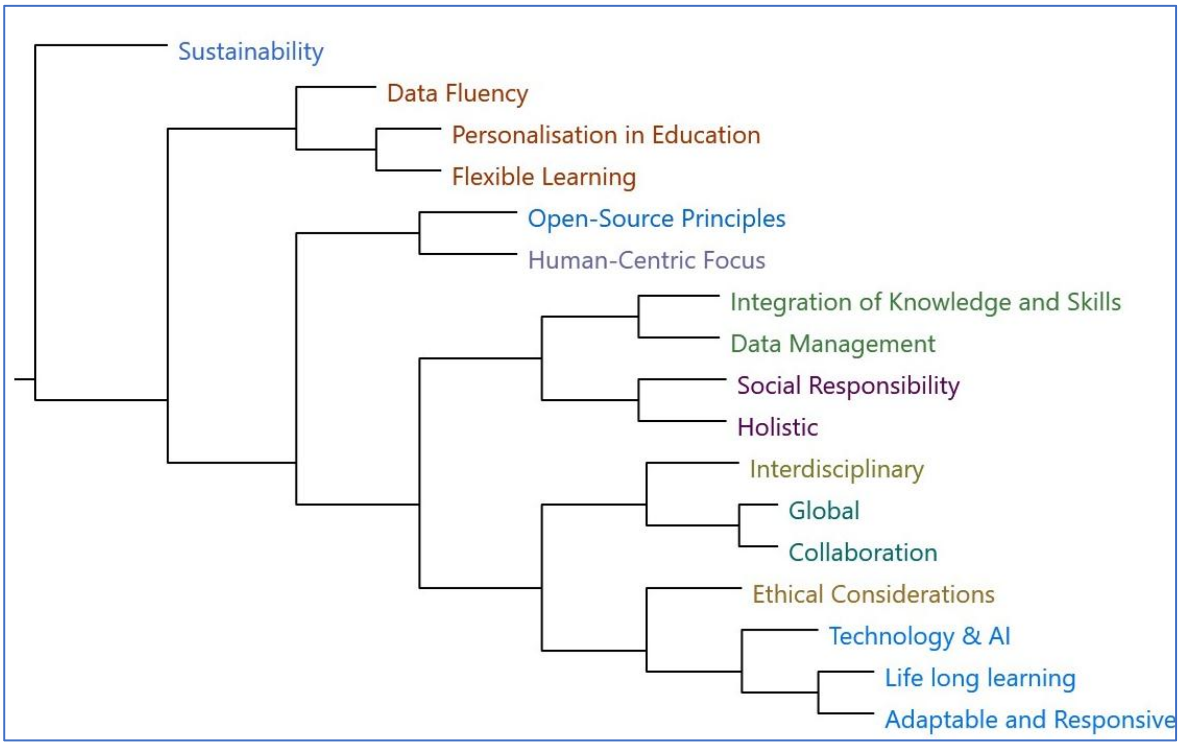


Figure 2-3:Phase 3: Searching for Themes. Example of how related codes were grouped into broader candidate themes

Throughout this phase, the researcher engaged in what Braun and Clarke (2021) describe as reflexive theme development, questioning what the themes were, why they mattered, and how they reflected value-laden assumptions in the literature. Some early groupings risked reinforcing existing silos, for example, separating "Technology & AI" into a primarily technical theme (automation, digital tools, data analytics) while locating ethics, inclusion, and societal consequences in a separate "social" theme. This partitioning implicitly reproduced a familiar divide between technical competence and human values, rather than treating them as interdependent. Such siloed categorisation felt misaligned with the interdisciplinary ethos of Industry 5.0 and the study's social constructionist position, which privileges relational and context-sensitive understandings. Categories were therefore collapsed and redefined. This was particularly true for the theme entitled Holistic and Human-Centric, which evolved from initially fragmented codes on wellbeing, empathy, and diversity toward a broader, values-driven paradigm.

2.4.1.4 Phase 4: Reviewing Themes

This phase involved a structured review process to move from candidate themes to a defensible final set. Consistent with Braun and Clarke's (2006, 2019) approach to theme review, candidate themes generated in Phase 3 were refined. This process led to several revisions that shaped the final set of seven themes. In particular, some early themes were collapsed where boundaries proved artificial or siloed, while others were redefined. For example, codes concerning wellbeing, empathy, inclusion, and supportive learning cultures were initially distributed across multiple tentative groupings but were subsequently consolidated to form a theme entitled Holistic and Human-Centric. This was because the coded extracts consistently pointed to a shared organising idea: engineering formation as relational and values-infused rather than purely technical. Similarly, codes relating to global responsibility and intercultural awareness were refined into a theme entitled Global and Cultural Perspectives to avoid overlap with Collaboration while retaining a clear conceptual core.

2.4.1.5 Phase 5: Defining and Naming Themes

Through this review, a final set of seven themes was constructed. They are: Technical Competency; Sustainability; Ethics and Social Impact; Collaboration Educational Approach; Global and Cultural Perspectives Holistic and Human-Centric

Theme names were selected to be conceptually precise and to signal their purpose within the model of Engineering Education 5.0. This step also involved translating themes into model "features" that would function as an evaluative framework. For example, Sustainability was defined not only as environmental awareness, but as a values-oriented commitment to long-term responsibility embedded in systems thinking and engineering decision-making. Ethics and Social Impact was similarly defined to include both the ethical implications of technology and engineers' societal responsibilities, positioning ethics as core constituent of engineering practice rather than a peripheral consideration. In the same way, Educational Approach was defined to capture pedagogical orientations (such as adaptability and lifelong learning) that enable graduates to work effectively amid uncertainty and change.

The final model thus reflects multiple dimensions of engineering education, signalling a rebalancing of priorities that moves beyond technical mastery toward relational, adaptive, and ethically grounded professional practice. This process reinforced the belief that model-building within a social constructionist paradigm is not just about extracting fixed truths from texts but constructing meaning through interpretive engagement with ideas and values.

It is noted that although resilience is articulated as one of the three core pillars of Industry 5.0, it is not presented as a discrete feature in the Engineering Education 5.0 model. Through the analysis, resilience was found to be a cross-cutting feature. So, to avoid duplication and conceptual overlap, it is embedded in multiple features:

- Educational Approaches: emphasises adaptable and lifelong learning-oriented pedagogies that equip graduates to respond to uncertainty, technological disruption, and socio-ecological crises
- Sustainability: highlights systems thinking and long-term responsibility in designing resilient socio-technical and ecological systems
- Collaboration: underlines the relational capacity to navigate complex multi-stakeholder environments and co-create responses to disruption, and

- Holistic and Human-Centric: stresses inclusive, supportive learning environments that foster wellbeing and enable students to adapt and thrive under pressure.

This model subsequently provides the analytical lens through which the data in this study are examined, and it informs the overall research design, as outlined in Chapter Three. The following sections provide an overview of each of the seven defining features of the Engineering Education 5.0 model, outlining their conceptual foundations and relevance to the broader aims of Industry 5.0.

2.4.1.6 Technical competency

Technical competency, in the context of Engineering Education 5.0, requires an integrated mastery of engineering knowledge and technical skills, equipping professionals for the challenges of a rapidly evolving technological landscape (Vogel, Lindner and Kratzsch, 2023). This feature transcends traditional engineering education by embedding cutting-edge technologies such as advanced data analytics and AI into the problem-solving toolkit (Gürdür Broo, Kaynak and Sait, 2022) preparing engineers to navigate complex, multidisciplinary challenges as well as empowering them to act as innovators who can harness technology to create meaningful societal impact. Technical competency, therefore, represents more than just skill acquisition; it is a dynamically evolving attribute that reflects the connection between technological advancements, educational equity, and institutional adaptability.

The literature underscores significant barriers to achieving this vision. Access to technology and infrastructure remains uneven, leaving gaps in the preparation of both students and institutions (Mourtzis, Angelopoulos and Panopoulos, 2023). Moreover, the shift to technologically driven methodologies necessitates a steep learning curve, where educators and students alike must adapt to new paradigms of teaching and learning (Al-Emran and Al-Sharafi, 2022). Faculty members, in particular, require professional development to effectively integrate these tools, with resistance to change further complicating the adoption of innovative pedagogical strategies (Mendonça, Pinto and Babo, 2020).

2.4.1.7 Sustainability

Sustainability, as part of Engineering Education 5.0, reframes the role of engineers as stewards of both technological innovation and ecological balance. This feature, which is also one of the three pillars of Industry 5.0 (Breque, De Nul and Petridis, 2021), emphasises the integration of ecological and societal considerations into every facet of engineering practice, fostering a generation of engineers who prioritise ethical, sustainable development alongside technical excellence. Central to this approach is the incorporation of sustainable practices through innovative educational strategies, such as project-based learning (Forcael, Garcés and Lantada, 2023), and the adoption of transformative technologies like extended reality (XR) and blockchain (Mourtzis, Angelopoulos and Panopoulos, 2023).

This pedagogical shift challenges traditional notions of engineering competency, urging students to grapple with the socio-technical implications of their work. By embedding sustainability into programmes, Engineering Education 5.0 equips graduates not only to design advanced technological solutions but also to ensure these solutions align with the principles of environmental stewardship and resource efficiency. The aim is to produce engineers who balance innovation with the long-term well-being of society and the planet (Forcael, Garcés and Lantada, 2023). However, achieving this vision requires more than just curriculum adjustments. It calls for an educational framework that instils a deep awareness of ecological interdependence and the far-reaching impacts of engineering projects. Students must learn to critically evaluate resource use, anticipate environmental consequences, and design for a future that reconciles technological progress with environmental resilience (Lantada, 2020). This approach of embedding sustainability into the DNA of engineering education, as per this feature, would empower graduates to lead with foresight, ensuring that engineering solutions not only meet the demands of today but also protect the resources and ecosystems of tomorrow.

2.4.1.8 Ethics and social impact

Ethics and social impact are central tenets of Engineering Education 5.0, emphasising the role that engineers play in shaping society through technological innovation. This feature emphasises the potentially far-reaching consequences of engineering decisions on ethical norms, social systems, and individual lives. To address these challenges, future engineers must be trained not only to develop technical solutions but also to critically evaluate and navigate their ethical and social ramifications (Forcael, Garcés and Lantada, 2023). Engineers must be encouraged to anticipate the broader consequences of their decisions, ensuring that technological advancements contribute positively to societal progress while adhering to ethical principles. Importantly, this feature also recognises the ethical dilemmas posed by emerging technologies, such as concerns surrounding data privacy, security, and the equitable deployment of digital tools in education (Al-Emran and Al-Sharafi, 2022; Gürdür Broo, Kaynak and Sait, 2022). Furthermore, this feature addresses issues of sustainability and social equity to mitigate the unintended consequences of innovation, which could help equip engineers with the skills to make informed, ethically sound decisions (Mazur and Walczyna, 2022; Murphy, Woschank and Pacher, 2022; Sangwan and Venugopal, 2022).

2.4.1.9 Collaboration

Collaboration, in terms of Engineering Education 5.0, addresses the necessity of interdisciplinary teamwork, cooperation with professionals from diverse fields, and engagement with society at large (Gürdür Broo, Kaynak and Sait, 2022). To advance this vision, Lantada (2020) advocates for the establishment of pan-European universities, enabling the exchange of students and faculty across borders. Such collaboration not only facilitates the sharing of ideas but also cultivates a global mindset, where engineers are equipped to address challenges with insights drawn from diverse cultural and disciplinary contexts. Similarly, Vogel, Lindner and Kratzsch (2023) emphasise strengthening partnerships between academia and industry. These collaborations allow students to engage with real-world workplace demands and challenges, supported by industry-provided teaching materials, case studies, and practical examples. By embedding collaboration at the heart of engineering education in the era of Industry 5.0, this feature seeks to prepare graduates not only as technical experts but as adaptive, team-oriented innovators capable of addressing multi-faceted challenges in a rapidly evolving world. Beyond institutional partnerships, this feature underscores the importance of equipping students with the skills to excel in multidisciplinary teams (Forcael, Garcés and Lantada, 2023). Developing this competency involves cultivating an awareness of teamwork dynamics and the ability to navigate complex group interactions effectively (Mercier *et al.*, 2023). However, implementing collaboration-focused programmes presents challenges. Designing programmes that effectively integrate various disciplines while offering a cohesive learning experience can be difficult (Andres *et al.*, 2022). Furthermore, the rapid pace of technological change often outstrips curriculum development processes, creating a lag in addressing emerging industry needs (Ghani, 2022). Traditional assessment methods also struggle to capture the nuances of interdisciplinary problem-solving and teamwork, raising concerns about the effectiveness and quality of new teaching approaches (Cuckov *et al.*, 2022).

2.4.1.10 Educational approach

The Educational approach advocated in Engineering Education 5.0 is rooted in the principles of continuous learning, adaptability, and the personalisation of education to address the evolving demands of society. This forward-thinking approach recognises the rapid pace of technological change and advocates for an educational framework that remains flexible and responsive without compromising the solid scientific and ethical foundations of engineering programmes, as discussed by Forcael, Garcés and Lantada (2023). They emphasise that the core mission of engineering universities, knowledge generation, technological innovation, and societal impact, remains unwavering. However, the specific content and delivery methods of engineering education must evolve to incorporate innovative resources that enrich this mission.

A key aspect of this approach is personalisation, which tailors education to the unique needs, interests, and career goals of individual learners (Lantada, 2020). By aligning curricula with student interests, engineering programmes can enhance motivation and learning outcomes while maintaining the rigour and standards necessary for scientific and technological excellence. This adaptability not only prepares students for immediate challenges but also instils a mindset of lifelong learning, equipping them to continually update their skills and redefine their roles in an era of constant technological advancement. The importance of lifelong learning in this educational model cannot be overstated. Gürdür Broo, Kaynak and Sait (2022) highlight the necessity of fostering continuous learning environments, particularly in the context of Industry 5.0, where engineers must frequently acquire new skills to remain relevant. There is an ongoing emphasis on adaptability for future engineers, who will face more frequent and profound changes in their professional landscapes than their predecessors.

2.4.1.11 Global and cultural perspectives

The penultimate feature of Engineering Education 5.0, Global and cultural perspectives, seeks to broaden the horizons of engineering students, equipping them with a global outlook essential for addressing complex, worldwide challenges (Lantada, 2020). This approach underscores the importance of situating engineering problems within a universal framework, enabling students to navigate and solve issues with a mindset that transcends national and cultural boundaries.

A critical element of this feature is fostering the ability to work effectively within culturally diverse teams. Engineers must not only recognise and appreciate cultural differences but also leverage them to communicate, collaborate, and innovate across cultural divides, as well as understanding the predominant Western approach to engineering and associated consequences (Cruz, 2021). By developing cross-cultural competencies, future engineers can design solutions that are contextually appropriate and globally impactful, ensuring their contributions resonate in diverse cultural and environmental settings (Van Maele *et al.*, 2023).

A global perspective also prepares graduates to play active and meaningful roles within the international engineering community. It empowers them to address a spectrum of challenges and opportunities on a global scale, from resource distribution and sustainability to technological innovation and ethical considerations (Byrne, 2023). Beyond problem-solving, the emphasis on cultural insights enables engineers to build bridges between diverse groups, enhancing teamwork and fostering inclusivity in multidisciplinary projects. Furthermore, developing cross-cultural awareness is increasingly vital in an era of human-machine collaboration, where engineers must integrate diverse perspectives into the design and operation of advanced systems. As Vogel, Lindner, and Kratzsch (2023) argue, these competencies are pivotal to navigating the complexities of multidisciplinary teams and harnessing the full potential of modern technologies.

Embedding global and cultural insights into Engineering Education 5.0 focuses on broadening the perspective of engineering students to encompass a worldwide viewpoint in order to face global challenges successfully. This approach emphasises the significance of understanding engineering problems within a universal framework and the ability to operate efficiently in diverse cultural groups. Moreover, it highlights the necessity for engineers to recognise and understand cultural differences, ensuring they can communicate and collaborate effectively beyond cultural divides and devise solutions that are suitable and successful in various cultural environments. The goal is to equip graduates with the capability to make meaningful contributions to the international engineering community by understanding and tackling the array (Gürdür Broo, Kaynak and Sait, 2022).

The globalisation of engineering practice presents both challenges and opportunities, particularly in relation to cultural differences in education and professional contexts. For example, Chung, (2015) illustrated how simulators can be used to train engineers in recognising and navigating diverse cultural approaches within engineering education. In light of this, it is essential that engineering education actively fosters cross-cultural competencies. These skills are increasingly important for effective collaboration in multidisciplinary teams and for maximising the potential of human-machine partnerships (Vogel, Lindner and Kratzsch, 2023).

2.4.1.12 Holistic and human-centric

The final feature of this Engineering Education 5.0 model promotes a holistic and human-centric approach, emphasising a comprehensive, people-focused strategy. This approach marks a transition to integrating technical know-how with a deeper understanding of the environments where engineering solutions are applied (Tavares, Azevedo and Marques, 2022). Human-centricity is one of the three pillars of Industry 5.0, suggesting that engineering education should equip learners not just with the requisite technical abilities but also with insights into the human elements at play. The objective is to nurture individuals capable of developing technology that benefits humanity, improves quality of life, and tackles real-world challenges in ways that honour human values and diversity (Gürdür Broo, Kaynak and Sait, 2022). Ensuring all students have equal access to learning opportunities and resources is a significant challenge (Gürdür Broo, Boman and Törngren, 2021) and accommodating diverse learning styles and needs in an advanced technological setting can be particularly difficult (Lantada, 2022; Shanahan and Organ, 2022).

2.4.1.13 Engineering Education 5.0 model

This section has considered the origins and influences of Engineering Education 5.0 and provided a revised model with seven features to be used for the present research study (Figure 2-4).

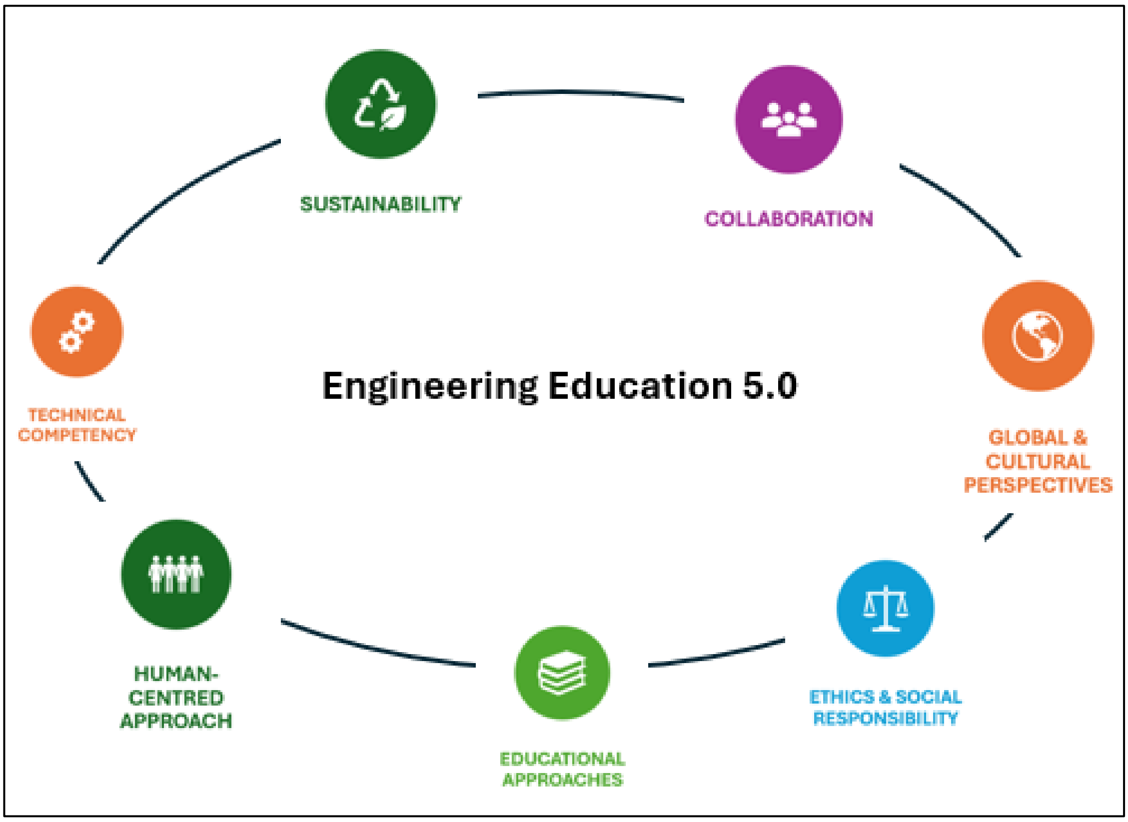


Figure 2-4: Model of Engineering Education 5.0

At this pivotal moment in history, as people navigate through an era filled with technological advancements and intricate social issues, Engineering Education 5.0 offers a template for moulding engineers who are equipped to tackle problems while acting as responsible citizens of the world, committed to fostering a more just, sustainable, and technologically proficient society. Nevertheless, the success of the proposed model depends on addressing several challenges. These include ensuring equitable technological access, resolving ethical quandaries, refining the curriculum and enhancing inclusivity (Lantada, 2020; Kopacek and Doyle-Kent, 2021; Al-Emran and Al-Sharafi, 2022; Bigan, 2022). The model was presented and discussed at SEFI 2024, where it received peer feedback at the annual SEFI 2024 conference in Lausanne (O'Gorman *et al.*, 2024). This process confirmed to the researcher its relevance as a framework for examining how accreditation interacts with emerging industrial and societal challenges.

The second overarching theme of this literature review now considers the influence of professional accreditation on engineering education, particularly in Ireland, before revisiting Engineering Education 5.0 in the final section, where both topics are considered in tandem.

2.5 The role of professional accreditation in the formation of an engineer

2.5.1 Engineering education research

Before delving into the specifics of accreditation, a brief overview of the field of Engineering Education Research (EER) is provided for context. EER has evolved over the past century, transforming from an informal interest in documenting and improving engineering education into a defined field of study (Johri, 2023). This development has been driven by the recognition of the need for a more rigorous, research-focused approach to improving engineering education outcomes. While interest in the topic can be traced back over a century, the formal establishment of EER as a discipline-based education research (DBER) field is a relatively recent phenomenon.

The shift towards the institutionalisation of EER has been particularly notable over the past few decades, with an emphasis on using systematic research methodologies to address educational challenges in engineering. The National Research Council (2012) in the US identified EER as a DBER field, recognising its interdisciplinary nature and its foundation in both engineering and educational research principles. This formalisation has led to the establishment of dedicated research-focused departments, doctoral programmes, research centres, journals, and conferences worldwide (Borrego and Bernhard, 2011; Bernhard, 2018).

Publications such as Heywood's (2005) book on EER have provided a theoretical and practical grounding for the field. Other volumes, including The Cambridge Handbook of Engineering Education Research (CHEER) (Johri and Olds, 2014) and more recently, The International Handbook of Engineering Education Research (IHEER) (Johri, 2023), have further expanded the extent of EER by introducing new topics, methodologies, and contributors. The publication of special issues in prominent journals, such as the *Journal of Engineering Education* and the *European Journal of Engineering Education*, has also played a role in disseminating research findings and fostering dialogue among scholars. Recent reviews of the field, such as those discussed in IHEER's Chapter Seven, provide a comprehensive overview of developments highlighting emerging trends and challenges.

In Europe, EER has experienced significant growth, reflecting the region's diverse cultural, economic, and institutional contexts. A key driver of this development is the SEFI (European Society for Engineering Education) network, which serves as a cornerstone for collaboration among engineering educators, researchers, and academic institutions across Europe. Founded in 1973, SEFI aims to foster excellence in engineering education through conferences, specialised working groups, joint research initiatives, and institutional partnerships. The annual SEFI conference serves as a platform for sharing cutting-edge research and best practices. The *European Journal of Engineering Education (EJEE)*, published by SEFI, is a leading venue for the dissemination of EER in Europe and has played a crucial role in advancing research within the European context.

Ireland has been an active contributor to EER, with its education system influenced by both European and global developments. Over the past two decades, EER in Ireland has gained momentum, supported by national policy frameworks, funding opportunities, and institutional initiatives. There exists a comprehensive corpus of research related to engineering education, spanning domains including, but not limited to, broadening participation (Conlon, 2008), online teaching (Mulligan *et al.*, 2007), assessment (Carthy, 2021), alternative pathways (Boyle *et al.*, 2022), careers (Chance, Direito and Mitchell, 2022), inclusivity (Murphy and Goodman, 2022), future skills (Beagon *et al*., 2019), and identity (Murphy, Chance and Conlon, 2015). Such a diverse range of EER underscores a vibrant ecosystem, offering avenues for in-depth exploration of pedagogical strategies, instructional delivery modalities, and diverse student demographics.

From a policy and accreditation perspective, Engineers Ireland, the professional body representing engineers in Ireland, has played a pivotal role in shaping EER. Its accreditation criteria, most recently updated in 2021, emphasises outcomes-based education, lifelong learning, and the development of transferable skills. These criteria align with the European Framework for the Accreditation of Engineering Education (EUR-ACE), ensuring that Irish engineering programmes meet international standards. Examples of relevant EER studies in Ireland include areas such as understanding sustainable development (Nicolaou and Conlon, 2016), outcomes-based education (Gallery, 2021), ethics (Homan, 2020; Martin, 2020), quality assurance (Kyne, 2021), and social justice (Murphy, Christensen and Conlon, 2022).

The next section considers EER literature, which has focused on accreditation criteria and the accreditation process as effective mechanisms for reflecting technological and societal changes in engineering education. It examines the context of quality assurance (QA) and the role of professional accreditation, before focusing on the specific perspective of Irish Higher Education Institutions (HEIs), and the impact of accreditation on the development of engineering programmes and the formation of engineers.

2.5.2 Quality in higher education

Quality has many definitions, interpretations and uses. In a linguistic sense, quality originates from the Latin term ‘qualis’, meaning ‘what kind of’ (Sahney *et al.,* 2004). The international definition of quality: ‘The degree to which a set of inherent characteristics fulfils requirements’ (ISO/IEC, 1999) is broad, which implies that in industry today there is no single accepted definition of quality. In higher education, Schindler *et al.* (2015) conducted a synthesis of the literature around the variety of definitions of quality and highlighted the plethora of challenges around a universal definition, not least the often conflicting approaches to quality of different stakeholders. Nevertheless, in higher education, the concept of quality is of little use without a system of measurement, accountability and improvement (Bloch *et al.*, 2021). This leads onto Quality Assurance (QA) where the focus in higher education in Ireland is driven by the large-scale adoption in Europe of the

Bologna Accord which was enshrined in Ireland in legislation as the National Framework for Qualification (NFQ) and the independent state agency responsible for QA in higher education is Quality and Qualifications Ireland (QQI) (QQI, 2022).

2.5.3 Quality assurance in higher education

UNESCO defines QA as “an ongoing, continuous process of evaluating (assessing, monitoring, guaranteeing, maintaining and improving) the quality of (an) education system, institution or programme” (UNESCO, 2013, p.2). According to the Standards and Guidelines for Quality Assurance in the European Higher Education Area, all QA activities encompass both accountability and enhancement (ESG, 2015). In essence, these elements foster confidence in the performance of a HEI. A well-executed QA system not only assures the institution and the public about the excellence of its activities (accountability) but also offers guidance and suggestions for improvements (enhancement). Therefore, QA and enhancement are closely linked. Together, they can cultivate a culture of quality that resonates with everyone, from students and faculty to the institution's leadership and administration (ESG, 2015). However, although national QA agencies remain in charge of setting standards and guidelines for higher education within their accredited institutions, the focus on QA for accountability and QA for enhancement varies among these agencies (Staring *et al.*, 2022).

QA is defined as “the collection of policies, procedures, systems and practices internal or external to the organisation designed to achieve, maintain and enhance quality”, while quality enhancement (QE) ‘is a process of augmentation or improvement’” (Harvey, 2004). However, the literature offers diverse viewpoints on the connection between QA and quality enhancement. While certain scholars believe that these two concepts operate independently and rarely intersect, others argue that they are deeply intertwined. Williams (2016) notes that whereas some see little interaction between the two, others consider them fundamentally linked. A viewpoint articulated by Danø and Stensaker (2007) suggests that QA and quality enhancement are intertwined components of a singular process. This cyclical perspective posits that each element informs the subsequent one, a perspective that aligns closely with the focus of this research.

Relating to the QA movement in higher education Tanweer and Qadri (2016) conclude that there is an increased emphasis on the engagement of a broad range of stakeholders such as students, staff, parents and employers. In a recent report from the European Universities Association (EUA), "Quality Assurance Fit for the Future", HEIs have expressed a desire for more guidance on specific aspects such as degree recognition, micro-credentials, and joint programmes. Conversely, they prefer not to have areas like governance and strategic management regulated. Importantly, modifications to QA practices should not increase the burden on academic and administrative personnel and should align with their intended objectives (EUA, 2023). The following section now moves to consider QA in higher education in Ireland.

2.5.4 Quality assurance in Irish HEIs

In Ireland, QQI is the independent state agency responsible for promoting quality and accountability in education and training services. It is a member of the European Association for Quality Assurance in Higher Education (ENQA), and its membership was renewed in 2019 following a review by an independent expert panel (QQI, 2022). The functions of QQI are to maintain a set of statutory QA guidelines (QAG), policies and criteria; approve and periodically review the effectiveness of providers' QA procedures, validate providers' programmes of education and training leading to QQI awards, delegate awarding powers to certain institutions, monitor quality, conducts focused reviews and conducts thematic reviews (QQI, 2022).

In HEIs, quality enhancement is generally exercised through the continuous improvement of academic council policies and procedures, and changes made in light of external examiner reports (Kyne, 2021). The definitions of QA mentioned earlier do not include any mention of accreditation. However, Westerheijden (2022) clarifies this by reframing a QA system in higher education as a combination of accreditation and evaluation systems. Here, accreditation is described as a structured and consistent evaluation method that culminates in a formal decision, leading to official approval processes for the institution, type of degree, or specific programme. Ryan (2015) suggests that accreditation can be used as a mechanism for ensuring quality in higher education, implying that accrediting a programme is an integral component of the broader QA process, validating its legitimacy in a professional context. However, intertwining accreditation, evaluation, and accountability in higher education QA frameworks can lead to significant challenges, such as "ensuring adequate rigour in QA" (Gray, 2009, p.31).

2.5.4.1 Function of accreditation bodies

To better understand the accreditation landscape in Ireland, QQI commissioned the Professional Body Accreditation in HEIs in Ireland (PARN), report where the primary focus was to explore the influence of professional body activities on the QA context of HEIs. The goal was to uncover potential advantages, address challenges, and foster stronger collaborations between QQI, HEIs, and professional entities (PARN, 2017). The report highlights statutory responsibilities, stating that "national quality assurance guidelines and institutions within Ireland are bound by European standards and guidelines. Similarly, many professional bodies are also bound by international agreements - for example, the Washington accord for engineers" (p.10). Some universities have created accreditation policies to pave the way to align the programmatic review and accreditation processes (PARN, 2017). Engineers Ireland, as outlined in the PARN report, is the designated Competent Authority for the engineering profession in Ireland under the EU Directive on the Recognition of Professional Qualifications (Kyne, 2021). As a response to the PARN report, the QQI Insights publication outlines the landscape of all the accreditation bodies in Ireland and outlines the challenges they face (QQI, 2018), for example, regularly updating standards as well as the costs associated with accreditation.

2.5.4.2 Positionality of accreditation bodies

Accreditation bodies in engineering education occupy a complex and often contested positionality (McNeil and Ohland, 2016). While they are typically framed as neutral, technocratic mechanisms dedicated to safeguarding public welfare and ensuring professional competency, a deeper analysis reveals that these entities operate within, and are shaped by, sociopolitical, economic, and cultural power structures. As Martin (2020) argues, accreditation processes are not ideologically neutral; instead, they reflect value-laden judgments about what constitutes legitimate engineering knowledge and education. Conlon (2013, cited in Martin, 2020) notes that accreditation panels are predominantly composed of engineers and industry representatives, often excluding voices from the wider community impacted by engineering decisions. They assert that this composition reinforces dominant norms and perspectives, privileging traditional technical competencies over broader social and ethical considerations. Consequently, the authority of accreditation bodies is not only regulatory but also deeply normative, with far-reaching implications for curriculum design, professional identity formation, and the future direction of engineering education.

Accreditation is commonly perceived as a technical and procedural undertaking, but it is, in fact, inherently political. Accreditation systems tend to be centralised and top-down in structure, deeply embedded within national cultures and traditions of higher education governance. This centralisation affords accreditation bodies considerable authority in defining what constitutes "good" engineering education, definitions that can become exclusionary if not regularly critiqued and diversified. As Lucena *et al.* (2008) argue that engineering education reform, including accreditation, is shaped by the complex interplay of governments, industry, professional organisations, and educators. Rather than being neutral, these processes reflect broader political, economic, and cultural negotiations that vary across national contexts. Consequently, as Chance, Martin and Deegan (2022) argue, accreditation systems do far more than regulate. They shape what is taught, how it is taught, and even what is valued in engineering education across jurisdictions. Accreditation, therefore, should be understood not merely as a quality assurance mechanism, but as a normative force with significant implications for curriculum, access, and professional identity.

Accreditation bodies derive their authority from state delegations of regulatory power and often operate under the assumption that they serve the public good. However, Klassen (2018) critiques this by showing that these assumptions do not always hold in engineering, where proactive oversight and disciplinary power are often lacking. Furthermore, Klassen asserts that accreditation policies are frequently developed by a relatively small group of individuals, raising concerns about representativeness, inclusion, and the dominance of certain interests, often those of older, majority-group engineers or industry leaders. This elite composition can result in accreditation practices that reinforce existing hierarchies. For instance, Harvey (2004) has pointed out that professional groups may act in ways that preserve their privileged status rather than serving the broader public interest.

Accreditation bodies must also be mindful of how global agreements, such as the Washington Accord, influence and sometimes standardise ethics requirements. While these accords aim to foster mutual recognition of accreditation standards, they also risk imposing homogenised frameworks, particularly in areas such as ethics, which may not reflect or respect local cultural values and contextual needs (Augusti, 2007).

From an Irish perspective, Homan (2020) highlights Engineers Ireland's significant bureaucratic influence on education and engineering practice, including control over the engineering curriculum and the criteria for becoming a chartered engineer. This influence extends to shaping engineers' professional development and ethical standards. His critique of Engineers Ireland's publications reveals a strong focus on authoritative perspectives and expertise, suggesting that little attention is paid to public involvement in technology and engineering decisions. The position of Engineers Ireland as a major influencer could, therefore, either hinder or support change in the engineering field, depending on a significant change in its perspective and alignment. This crucial role makes their support vital for any shifts in engineering education and practice (Homan, 2020), which raises the question of whether this entails a fundamental alteration in Engineers Ireland’s stance from experts in authoritative knowledge to advocates for the integration of engineering disciplines, non-technical fields, and society.

Accreditation bodies, therefore, are not passive gatekeepers of educational quality. They are active participants in shaping the engineering profession through their policies, standards, and practices. Their positionality, including who they are, whom they represent, and the values they embed in their decisions, matters in the broader context of engineering education.

2.5.5 Accreditation and the formation of an engineer

Accreditation shapes the structure, content, and ethos of engineering education. Beyond ensuring academic quality, it influences how engineers develop their professional identities, ethical sensibilities, and understanding of social responsibility. Alam and Kootsookos (2020) present accreditation as a platform for advancements in engineering education. They view it as an intertwining of the transnational nature of engineering and academic quality assurance.

Accreditation and assessment play a crucial role in ensuring the quality of engineering graduates and the technical workforce (Patil and Codner, 2007). However, existing models, both regional and international, are often inconsistent, complex, and lacking in transparency. This creates confusion and raises concerns about mutual recognition and global mobility within the engineering profession. To this end, a comprehensive insider study on accreditation as part of the wider QA process in engineering education in Ireland by Kyne (2021) who outlined the two predominant QA methods: validation and accreditation. On the one hand, validation or revalidation, known as 'programmatic review' within Institutes of Technology and Technological Universities, is an internal process managed by the HEI. On the other hand, accreditation is an external procedure evaluated by the relevant professional body. The accreditation processes assess various facets of engineering education and have distinct self-evaluation procedures carried out by the programme teams (Kyne, 2021). On the other hand, accreditation is an external procedure evaluated by the relevant professional body. The accreditation processes assess various facets of engineering education and have distinct self-evaluation procedures carried out by the programme teams (Kyne, 2021. However, as Chance *et al.* (2021) argue, while accreditation frameworks like the Washington Accord formally embed ethical and sustainability outcomes, in practice these dimensions are often treated implicitly, folded into broader categories like health and safety, and rarely addressed directly.

Practical examples illustrate how accreditation processes can shape core educational principles within engineering education. For instance, ABET responded to high-profile engineering failures, such as the Challenger shuttle disaster, by strengthening requirements for ethics education across all accredited engineering programmes (Downey *et al*, 2015). A contrasting cultural perspective is offered by the Japanese accreditation body, JABEE, which places emphasis on developing engineers who can “consider issues from a point of view that rises above self-interest, overcomes selfish immaturity, and locates one's concerns and interests in relation to those of others engaged in the general pursuit of harmony” (p. 87). Accreditation systems also serve to differentiate between fields within engineering education. For example, separate accreditation criteria are used to distinguish between engineering and engineering technology programmes (Murphy, Chance, and Conlon 2015). Moreover, Byrne (2023) critically examines professional accreditation in relation to sustainability and broader societal imperatives, questioning whether current frameworks place excessive or insufficient demands on higher education institutions in this regard.

Accreditation frameworks often define what constitutes legitimate knowledge in the field of engineering. These frameworks, such as those developed by Engineers Ireland, ABET or under the Washington Accord, focus heavily on technical competencies and measurable outcomes, often reducing transversal skills to checklists of learning objectives. Kabo and Baillie (2009) argue that accreditation systems reinforce technocentric models of engineering by focusing on what is teachable, measurable, and marketable, thereby narrowing students' exposure to critical ethical and social thinking, for example. Cech (2014) identifies a “culture of disengagement” (p.42) in engineering education where students are socialised to prioritise technical work over social context or ethics, a culture that is often reproduced by accreditation standards.

Accreditation frameworks define attributes of a competent graduate, which present the identity of the engineer as a technically skilled, rational, and apolitical actor. (Pawley, 2009) This often leaves little space for more relational, inclusive, or justice-oriented conceptions of engineering. Downey *et al.* (2006) show that global accreditation models tend to promote a universal model of engineering that reflects Western industrial norms, reinforcing a narrow vision of who counts as an engineer.

Accreditation can also influence how curricula are designed and delivered. The demand for clearly defined learning outcomes and assessments may discourage faculty from using exploratory or reflexive pedagogies. Beder (1999) points out that accreditation can function as a mechanism of professional control, pushing universities to align with industry-driven, efficiency-focused models that marginalise critical and ethical education. In a more recent study, Gallery (2021) notes that outcome-based accreditation has reshaped engineering programmes to focus more on performance metrics, sometimes at the expense of deeper learning outcomes like ethical judgment. Accreditation is not inherently restrictive; it can also serve as a lever for positive change. Lucena, Schneider and Leydens (2010) advocate for transforming accreditation from a compliance model to one that empowers ethical and socially responsible engineering practices. Leydens and Lucena, (2017) provide pedagogical models within engineering education that could be supported, not stifled, by enlightened accreditation policies.

Therefore, accreditation can play a pivotal role in shaping engineers not just as technically competent professionals, but also as ethical actors and citizens. Whether accreditation supports a narrow, technocratic identity or a broader, justice-oriented one depends on how it is designed, interpreted, and enacted.

2.5.6 Accreditation standards in Ireland

In Ireland, accreditation criteria are developed by Engineers Ireland based upon international standards. Engineers Ireland is a member of the International Engineering Alliance (IEA) as well as the Engineering Network for Accreditation of Engineering Education (ENAEE), both of which heavily influence the formation of the text for accreditation criteria. The IEA has oversight of three international accords that determine the necessary level of education for an engineering qualification. The Washington Accord, signed in 1989, defines the qualifications required of a Chartered Engineer (NFQ level 8). The Sydney Accord, signed in 2001, defines the qualifications required of an Associate Engineer (NFQ level 7). The Dublin Accord, signed in 2002, defines the qualifications required of an Engineering Technician (NFQ level 6). Through these accords, the signatories accept each other’s accreditation decisions thereby, enabling mutual recognition of each signatory’s engineering degree programmes (Grimson and Murphy, 2015). International review teams periodically assess Engineers Ireland’s criteria to ensure that accreditation processes are performed to the correct standard (ENAEE and the three IEA Accords) (QQI, 2018).

Engineers Ireland’s approach to accreditation standards or criteria is outcome-based education (OBE), originally proposed by the USA accreditation body ABET (ABET, 1998) and known as Engineering Change or EC2000. Engineers Ireland is silent on delivery modes for programme methods and gives little guidance on pedagogy (Gallery, 2021). In fact, Heywood

(2016) argues that EC2000 (ABET, 1998) was developed without sufficient consideration of student involvement and that this oversight has not been corrected in more recent proposals from ABET. On the other hand, Murphy and Ringwood (2016) maintain that accreditation standards based on outcomes are now the norm, offering more flexibility in programme design and delivery methods. Engineers Ireland also contends that in Ireland, there is a wide range of stakeholders involved in developing accreditation criteria (Engineers Ireland, 2021).

While debates continue around the flexibility and limitations of outcome-based accreditation frameworks, attention has also turned to how specific outcomes, such as ethics, are interpreted and implemented within engineering programmes. Ethics was first introduced as a standalone programme outcome (PO) by Engineers Ireland in 2007. In a comprehensive study of ethics in engineering education based on the 2014 accreditation version (Martin, 2020) found an "unsystematic implementation of ethics in the engineering curriculum" (p.312), as well as identifying challenges faced by members of accreditation panels in the evaluation of ethics, "given the role that accreditation recommendations have in shaping the engineering curricula" (p.313). Martin (2020) makes several recommendations to Engineers Ireland at a policy level; however, there is limited research evidence to indicate whether those recommendations were considered in the latest 2021 accreditation criteria.

Building on this critique, other scholars have examined the treatment of ethics in engineering education through alternative lenses, such as sustainability and societal responsibility. Homan (2020) examines ethics in engineering education and practice through a sustainability lens, highlighting how the 2021 Programme Outcomes related to ethics are "phrased in such an open manner…as to be open to a range of interpretations" (p. 56). He also presents evidence that engineering is often viewed as fulfilling a narrow technocratic role, a perception that continues to shape the prevailing ideology in engineering education. This perspective is particularly relevant to the present research, which considers how the pillars of Industry 5.0 respond to the technological determinism embedded in Industry 4.0. While Homan advocates for Engineers Ireland to reframe future criteria, there is no indication that his study influenced the 2021 revisions.

A further Irish study on education for sustainable development highlights that current efforts primarily emphasise the environmental aspect while largely sidelining the social dimension (Nicolaou *et al.*, 2018). The researchers found that "concern about professional accreditation was identified as the most significant influence on programme design" (p.11). They conclude that it is concerning that the 2014 accreditation criteria fail to reference sustainable development explicitly.

Overall, research conducted on the 2014 Engineers Ireland criteria demonstrates that the accreditation body itself is a powerful driver and influence of programme development. However, there are differing views on the impact that changing standards can have on the professional formation of a graduate. Martin and Deagon (2022) observe that Engineers Ireland has adopted an online review method as the standard for gathering and presenting evidence for accreditation endeavours.

On the global stage, it has been acknowledged that accreditation bodies from ABET in the US to JABEE in Japan have an influence on the incorporation of, for instance, ethics into engineering education (Downey *et al*., 2015). This further demonstrates the powerful position that accreditation bodies, such as Engineers Ireland, can have in promoting updated approaches to the attributes that graduates are expected to possess.

In summary, regular revisions of accreditation criteria and processes can be effective in reflecting technological and societal changes in engineering education, but they also come with challenges. Balancing the need for rigorous standards with flexibility, engaging diverse stakeholders, and managing the administrative burden are critical factors in ensuring that accreditation remains a valuable tool for enhancing the quality and relevance of engineering programmes. The final section of this chapter now considers prior research at the intersectionality of Engineering Education 5.0 and professional accreditation.

2.6 The intersectionality of Engineering Education 5.0 and professional accreditation

Grounded in the scholarly literature, the current model of Engineering Education 5.0, presented in Section 2.4.1 provides a comprehensive incorporation of the pillars of Industry 5.0 into engineering education. In addition, as discussed in section 2.5, accreditation criteria may serve as a vehicle for developments in engineering curricula (Martin, 2020), which ultimately can influence how engineers are formed. Therefore, the intersectionality of these two topics now encompasses Engineering Education 5.0 research conducted in relation to accreditation and, more specifically, the latest Engineers Ireland criteria from 2021.

At a strategic level, when considering a framework for Engineering Education 5.0, Lantada, (2020) opines that institutions are hindered by bureaucratic procedures related to verifications, accreditations, and reaccreditations, which impede their ability to respond promptly to changes in science and technology. This bureaucratic inertia could be considered a constraint of engineering education, which it is posited necessitates a more agile and immediate integration of advancements. Looking ahead to 2030 and beyond, a shift towards continuous monitoring, potentially facilitated by AI tools, could replace periodic evaluations and accreditations, enhance cost and time efficiency, and foster a more responsive educational ecosystem. This is a challenge that warrants further exploration.

The limited body of research examining Engineers Ireland's 2014 accreditation criteria, particularly the enhancement of the ethics PO, offers valuable insights into the evolving role of accreditation in shaping engineering education (Homan, 2020; Martin, Conlon and Bowe, 2021). These studies illustrate how accreditation reforms influenced Engineers Ireland, HEIs, and the broader EER community, thereby signalling the need for renewed investigation into the more recent 2021 accreditation criteria (Engineers Ireland, 2021).

To date, there is little evidence of comprehensive research focusing on the 2021 criteria in an Irish context. Byrne (2023), while not explicitly framing the study within the lens of Engineering Education 5.0, compares the sustainability and equality, diversity, and inclusion (EDI) components of Engineers Ireland's 2021 criteria with those of other international accreditation agencies. Byrne notes that sustainability now appears fifteen times and diversity five times in the 2021 document, an increase from just five references to sustainability in the 2014 version (Engineers Ireland, 2014; 2021). This suggests a growing emphasis on these themes in accreditation policy.

Further indications of the criteria's influence can be seen in other recent studies. Beagon *et al*., (2021) acknowledge that the 2021 accreditation requirements have shaped programme design, while dePaor *et al*., (2022) consider student perceptions of professional skills development in light of the new criteria. These studies reflect a growing appetite to explore the implications of accreditation on engineering education. However, no research to date has directly examined how the principles of Engineering Education 5.0 inform or align with the 2021 accreditation criteria, or how these principles are influencing programme development within Irish HEIs.

Internationally, accreditation bodies are also responding to the shifting demands of Industry 5.0. For example, ABET in the United States is considering adding a data science requirement to all engineering programmes (Cuckov *et al.*, 2022), signalling a broader move towards integrating technological and data fluency as core competencies. This trend reflects key themes of Engineering Education 5.0, which responds to Industry 5.0 by prioritising human-machine collaboration, data-driven skills, and ethical awareness.

Within this evolving context, scholars such as Sangwan and Venugopal (2022) argue that Engineering Education 5.0 demands a stronger focus on practical application, integrated with theoretical knowledge and underpinned by transversal skills. Lantada (2022) anticipates that international accreditation bodies will begin to incorporate these principles in the coming decade. At the institutional level, university leadership may also be prompted to redesign curricula in line with the human-centric, sustainable, and digital competencies promoted by Engineering Education 5.0.

Broo, Kaynak and Sait (2022) reinforce this trajectory by identifying key future directions for engineering education. They recommend the inclusion of lifelong learning, transdisciplinary education, sustainability, resilience, human-centric design, data literacy, and human-machine interaction as core components of future programmes. While their recommendations are conceptually aligned with Engineering Education 5.0, they do not offer guidance on how these changes should be operationalised, particularly in relation to accreditation frameworks. This omission presents an opportunity for further research into how such recommendations could be reflected in POs and PAs within Engineers Ireland's 2021 accreditation criteria.

In light of this, there is a clear and pressing need for scholarly inquiry into how accreditation frameworks are evolving in response to the principles of Engineering Education 5.0. As Lantada (2022) notes, accreditation agencies play a pivotal role in shaping engineering curricula, meaning their decisions and guidelines are likely to significantly influence the adoption of Engineering Education 5.0 over the coming years. Yet, the academic literature on this topic remains limited, underscoring the importance of research that explores how accreditation can serve as a mechanism for embedding Engineering Education 5.0 into engineering programmes in Ireland and beyond.

From the above discussion, the current immature state of published literature on the intersectionality of research, which considers the impact of Industry 5.0 on engineering education and the latest accreditation criteria from Engineers Ireland 2021, offers a unique research opportunity and a chance to contribute to new knowledge, especially at a time of such rapid change. Therefore, emerging from the above discussion, the overarching research question guiding this study is:

Through the lens of Engineering Education 5.0, how does accreditation in engineering programmes at a Higher Education Institution in Ireland prepare students for Industry 5.0?

To explore the overarching research question, three sub-questions were developed. These focus on different phases of the accreditation process:

- *Through the lens of Engineering Education 5.0, how do members of the accreditation board of Engineers Ireland understand the current accreditation criteria?*
- *How is Engineering Education 5.0 represented in the 2021 Engineers Ireland Accreditation Criteria?*
- *How is Engineering Education 5.0 represented in the programme outcomes in the self-assessment reports produced as part of accreditation in a HEI in Ireland?*

As explained in Chapter One, these sub-questions are structured to align with Ball's (1993) policy cycle framework, which conceptualises policy as a dynamic process enacted across multiple contexts. The first sub-question maps onto the context of influence, highlighting how accreditation criteria are shaped through stakeholder negotiation and interpretation. The second relates to the context of text production, focusing on how the 2021 Engineers Ireland Accreditation Criteria codify policy priorities. The third corresponds to the context of practice, examining how accreditation texts are interpreted and enacted within higher education institutions. This framing complements the study's social constructionist orientation by recognising accreditation as a process through which understandings of Industry 5.0 analysed through the lens of Engineering Education 5.0 are produced, negotiated, and operationalised. The methodological approach of the present study and the research design is outlined in the next chapter.

Chapter 3: Research methodology

3.1 Introduction

This research sought to examine how Engineering Education 5.0 is constructed through accreditation practices in engineering programmes in an Irish HEI. To answer this overarching question, rich data were required to uncover descriptions, understandings, and meanings about accreditation practices in engineering education and Engineering Education 5.0. As outlined in Chapter Two, professional accreditation plays a central role in shaping engineering education in Ireland, with programmes designed to prepare graduates for the emerging challenges of Industry 5.0, as conceptualised in the Engineering Education 5.0 model presented in Section 2.4.1 This chapter describes and justifies the methodological approach employed in the research as well as the research methods used. It is organised around five main sections: the methodological approach adopted, the research design, the range and extent of data collected, the method of data analysis, and the ethical issues considered.

3.2 Methodological approach

3.2.1 Research strategy: Qualitative

A qualitative research strategy was deemed the most appropriate for this study. This was because the research sought to explore an aspect of the social world, and the researcher was the primary instrument through which data is gathered and interpreted (Rossman and Rallis, 2017). Building on this, Denzin and Lincoln (2011) describe qualitative research as a "situated activity that locates the observer in the world" (p.3) and involves a set of interpretive practices that reveal the world. These practices enable researchers to study phenomena in natural settings, aiming to interpret and understand them through the meanings ascribed to them by participants. Acknowledging the existence of multiple realities shaped by participants' diverse perspectives and subjectivity of participants, qualitative research is thus particularly valuable for understanding perspectives and exploring the meanings individuals or groups assign to social problems (Creswell and Creswell, 2018). It is also well-suited for studies that require deep insights into complex issues or the context in which participants engage with those issues (Marshall and Rossman, 2014). For these reasons, a qualitative approach was deemed suitable for this study, which sought to explore how engineering education in Ireland prepares engineers. This research question demanded a complex, detailed understanding of the accreditation process within engineering education.

3.2.2 Researcher's philosophy: Social constructionism

This study adopts the philosophical position of social constructionism, which rests on the belief that "meaning is not discovered but constructed," and that different individuals may interpret reality in distinct ways (Crotty, 1998, p.9). Knowledge and meaningful reality thus arise from human practices, which are constructed through "interactions between individuals and their environments and developed within a social context" (p. 42). There are no absolute or universally valid interpretations, only interpretations accepted within particular cultural frameworks, which remain open to challenge. Individuals share customs and values within their societies that shape their culture, and that meaning emerges from their interaction with the world and personal biases (Crotty, 1998; Denzin and Lincoln, 2011). Knowledge is thus viewed as subjective, shaped by cultural and societal norms, as well as individual values and social interactions (Sorensen *et al.*, 2022).

The critical assumptions of social constructionism align closely with the researcher's understanding of engineering education in Ireland, particularly in recognising that it is not a fixed or universally defined concept, but one shaped by cultural, institutional, and contextual factors. These assumptions allowed the research to move beyond conventional understandings of engineering education and instead explore how its meaning is actively constructed by various stakeholders, including educators, policymakers, and accreditation bodies. Crotty (1998) encourages researchers to approach phenomena "in a radical spirit of openness to its potential for new meaning" (p. 51), a stance that proved essential in examining how engineering education is interpreted and enacted within the Irish context, especially in light of evolving accreditation standards and Engineering Education 5.0 imperatives. Therefore, by adopting a social constructionist perspective, this study views knowledge as inherently subjective and shaped through language, culture, and individual worldviews (Sorensen *et al.*, 2022). Accordingly, the research seeks to explore the diverse ways participants interpret and make sense of their involvement in the engineering education accreditation process.

In addition, social constructionism emphasises the social and relational processes through which knowledge is co-created. In this context, the researcher's background, as an engineering educator and industry professional with over three decades of experience, forms an integral part of the meaning-making process. This insider perspective is acknowledged as a potential source of bias and a valuable resource for interpreting participants' narratives with depth and contextual understanding.

3.2.3 Methodological choice: Case study

This research adopts a case study approach, which aligns with a social constructionist perspective by emphasising the importance of understanding complex phenomena within real-life, contextual settings (Merriam, 1998; Yazan, 2015). This approach also supports the use of multiple methods to generate in-depth, interpretive insights, reflecting the view that knowledge is constructed through interaction and shaped by the meanings individuals assign to their experiences (Johansson, 2007; Rashid *et al.*, 2019).

Specifically, this research employs an exploratory case study design, an approach used to gain initial insight into a phenomenon through close examination of a unique situation (Yin, 2018). Exploratory case studies are particularly valuable in contexts where theoretical frameworks are limited, enabling researchers to identify patterns, generate insights, and inform future research directions (Yin, 2018). The phenomenon in this research - engineering education in the era of Industry 5.0 - is an emerging and underexplored area. Use of an exploratory case study enables a nuanced, in-depth investigation of a single organisation's (Engineering Ireland) interpretation and implementation of Engineering Education 5.0, capturing diverse perspectives, including conflicting viewpoints (Stake, 1995; Merriam, 1998; Johansson, 2007).

There are a number of benefits to this approach. The case study's bounded nature supports the exploration of individuals, groups, or organisations within well-defined temporal and geographical contexts (Cohen, Manion and Morrison, 2017). Additionally, the exploratory design facilitates understanding of how and why institutions engage with new educational paradigms, revealing key drivers and barriers to change (Yin, 2018). This approach also integrates description, analysis, and interpretation, aligning with the belief that knowledge is constructed and the existence of multiple realities (Baxter and Jack, 2008). Finally, case study is associated with methodological flexibility, enabling the use of multiple data collection methods, thus enhancing depth and reliability through triangulation (Pearson, Albon and Hubball, 2015; Rashid *et al.*, 2019).

Yin (2018) highlights the value of exploratory case studies for examining contemporary, complex issues lacking established theoretical frameworks. As discussed in Chapter One, approaches in engineering education to meet the needs of Industry 5.0 are emergent. The exploratory approach adopted in this research supports methodological flexibility, enabling responsiveness to emerging insights, the development of new conceptual understandings, and contributions to future research and policy development in engineering education. The case study design allows for the integration of multiple qualitative methods, both to enhance depth and reliability (Pearson, Albon and Hubball, 2015; Rashid *et al.*, 2019) and to enable more meaningful interpretation (Braun and Clarke, 2019).

3.2.4 Research methods

Two research methods were employed in this exploratory case study: interviewing and document analysis. These methods were chosen for their suitability in generating rich, contextualised insights into participants' experiences and the meanings they attribute to them, an approach consistent with a social constructionist perspective.

3.2.4.1 Interviewing

Interviews were selected as a key research method in this study. Social constructionism recognises that knowledge is co-created through dialogue and interaction; therefore, interviews provide a valuable space for participants to articulate their interpretations of the accreditation process. As Kvale and Brinkmann (2009) highlight, qualitative interviews are particularly effective for eliciting participants' lived experiences and interpreting the meaning of those experiences. Interviews are not merely data-gathering exercises, but social and emotional interactions in which participants voluntarily share their perspectives. The quality of this exchange is shaped by both verbal and non-verbal communication, as well as the relational dynamic between interviewer and participant (Young *et al.*, 2018). In case study research, interviews offer particular value as they can focus directly on the case and yield rich, explanatory insights, including perceptions, attitudes, and meanings (Yin, 2018). They serve multiple research functions, evaluating individuals, exploring or testing hypotheses, collecting data, or gauging opinions, making them especially suitable for studies aiming to understand experience (Cohen, Manion and Morrison, 2017).

Semi-structured interviews were chosen for their flexibility, allowing the researcher to adjust question wording, order, or introduce new topics in response to the flow of conversation. This adaptability is particularly important given participants' varying levels of subject knowledge (Kvale and Brinkmann, 2009). The one-to-one, semi-structured interviews conducted in this study are well-suited to exploring experiences within a social unit such as an engineering programme, offering insights into how specific phenomena are understood and shaped by individuals in these contexts.

3.2.4.2 Document analysis

Document analysis complements interviewing by uncovering the socially embedded discourses, values, and assumptions present in formal texts, enabling a deeper understanding of how meaning is constructed and conveyed within the institutional context of engineering education. Document analysis is a well-established method in qualitative research, with any text-containing document serving as a potential data source (Patton, 2002). The use of document analysis in this research is justified for several reasons. First, documents are frequently used alongside other qualitative methods to enhance the credibility of findings by corroborating evidence from multiple perspectives and reducing potential biases (Denzin, 1978). Second, document analysis aligns well with qualitative case studies that aim to produce detailed accounts of specific phenomena, events, organisations, or programmes (Stake, 1995; Yin, 2018). Third, documents are not neutral repositories of information but socially constructed texts that reflect knowledge, values, actions, and relationships (Fairclough,2003). As such, they offer valuable insights into a wide range of research topics (Bowen, 2009). This includes both public and user-generated documents, each contributing distinct perspectives.

However, researchers should remain mindful of the limitations of document analysis related to validity, reliability, and bias, as documents are typically not created for research purposes (Cohen, Manion and Morrison, 2017) and these concerns must be considered during both selection and analysis (Bowen, 2009). Document choice should align with the study's research questions and objectives, taking into account both content and the social context of production (Prior, 2003). It must also be recognised that documents are dynamic entities, embedded within and reflective of broader social realities (Khan and Slotta, 2020). Applying these criteria helps ensure the reliability and validity of documents used in qualitative studies. The formal and reflective texts that are an essential aspect of accreditation were used as data in this study. They include the Engineers Ireland Accreditation Document (EIAC) and programme self-assessment reports (SARs) created by Engineers Ireland and a HEI programme boards respectively. These documents were particularly well-suited to document analysis, given their central role in shaping and reflecting engineering education policy and practice. They were treated in this study as discursive artefacts that codify and construct educational priorities. From a social constructionist perspective, they are understood as texts in which meaning is negotiated rather than as objective statements of fact. Moreover, their structured and purposive nature, provides a basis for examining how Industry 5.0 is framed, interpreted, and operationalised within engineering programmes in a HEI.

Reflexively, it is acknowledged that the interpretation of these documents is shaped by the researcher's professional background in higher education and by a theoretical orientation towards Industry 5.0 as an emergent paradigm. These positionalities influenced the analytical focus explored in the texts. Accordingly, the analysis seeks to illuminate the ways in which Industry 5.0 is discursively constructed and embedded within engineering programmes in a HEI in Ireland via the EIAC and the programme outcomes section of SARs.

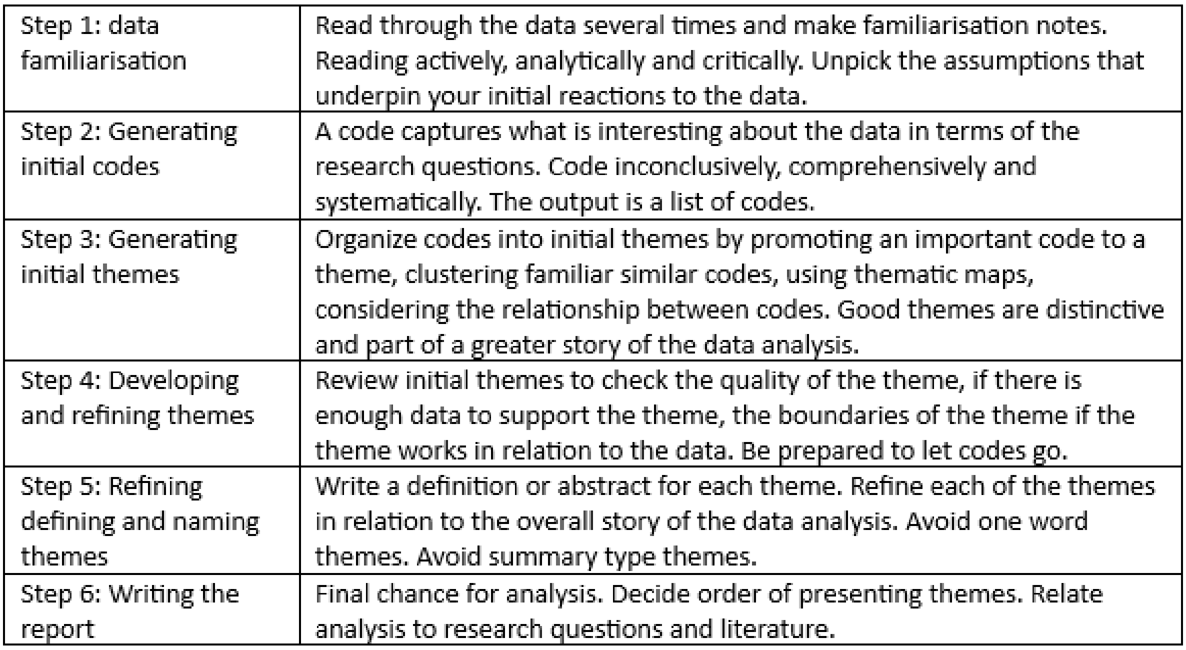
3.2.5 Approach to data analysis

3.2.5.1 Reflexive thematic analysis

Qualitative data analysis involves compiling, disassembling, reassembling, and interpreting data to produce meaningful conclusions (Yin 2015). This study applied such an approach to documents and interview transcripts, aligning with Cohen *et al.'s*, (2017) emphasis on the value of using multiple data sources to reflect diverse participant perspectives.

Braun and Clarke's (2019) reflexive thematic analysis (RTA) was the approach to data analysis adopted in this research and was selected for its compatibility with the study's social constructionist underpinnings. It positions the researcher as an active agent in meaning-making, where codes reflect interpretive engagement rather than objective truths (Braun and Clarke, 2019, 2020). RTA embraces subjectivity, reflexivity, and flexibility, eschewing consensus or replicability in favour of richer interpretations. The method allows themes to emerge iteratively, evolving with increasing familiarity with the data. While Braun and Clarke (2006) originally framed thematic analysis as adaptable across paradigms, later developments position it firmly within qualitative, constructionist traditions. Its alignment with this study's theoretical assumptions makes it a fitting choice for addressing the research questions while respecting participants' subjectivity and the researcher's role. Braun and Clarke's (2012, 2013, 2020) six-phase model guided the analysis (see Table 3-1). Though presented sequentially, the process is recursive and iterative, allowing revisitation of earlier stages as interpretations evolve.

Table 3-1: Phases adapted from Braun and Clarke's (2019) Reflexive thematic analysis framework



Step 1: data familiarisation	Read through the data several times and make familiarisation notes. Reading actively, analytically and critically. Unpick the assumptions that underpin your initial reactions to the data.
Step 2: Generating initial codes	A code captures what is interesting about the data in terms of the research questions. Code inconclusively, comprehensively and systematically. The output is a list of codes.
Step 3: Generating initial themes	Organize codes into initial themes by promoting an important code to a theme, clustering familiar similar codes, using thematic maps, considering the relationship between codes. Good themes are distinctive and part of a greater story of the data analysis.
Step 4: Developing and refining themes	Review initial themes to check the quality of the theme, if there is enough data to support the theme, the boundaries of the theme if the theme works in relation to the data. Be prepared to let codes go.
Step 5: Refining defining and naming themes	Write a definition or abstract for each theme. Refine each of the themes in relation to the overall story of the data analysis. Avoid one word themes. Avoid summary type themes.
Step 6: Writing the report	Final chance for analysis. Decide order of presenting themes. Relate analysis to research questions and literature.

Two key considerations from Braun and Clarke (2019) informed the approach to the data analysis: first, that their six-phase framework is not a prescriptive 'recipe' but should be adapted to suit the research context; and second, that themes do not simply 'emerge' from the data but are constructed by the researcher, who played a pivotal role in interpretation. This aligns with the study's social constructionist epistemology.

3.2.5.2 Computer-Assisted Qualitative Data Analysis Software (CAQDAS)

CAQDAS has become an essential tool in qualitative research, offering a range of benefits for both document analysis and thematic analysis. In document analysis, CAQDAS enhances the efficiency and depth of data interrogation. By facilitating the organisation and retrieval of data, these tools enable researchers to manage large volumes of documents systematically (Silver and Lewins, 2014). This systematic approach is critical when dealing with diverse and complex data sets. Additionally, CAQDAS software provides advanced coding mechanisms, allowing for the meticulous and structured categorisation of data. This enhances the credibility and reliability of the analysis by ensuring consistency in the coding process, which is often a challenge in manual methods (Jackson *et al.*, 2019). Similarly, in the analysis of qualitative data, CAQDAS tools offer distinct advantages. One of the primary benefits is the ability to facilitate the identification and development of themes through sophisticated coding and data-linking features (Braun and Clarke, 2006). This is useful in RTA, where identifying patterns and themes within the data is central. CAQDAS software provides visual tools, such as mind maps and concept maps, which aid in the visualisation and exploration of relationships between themes, enhancing the depth of analysis (Paulus, Lester and Dempster, 2014). Nvivo 12 Plus software was the CAQDAS tool used in this study.

In summary, this section, described and justified each element of the research strategy, how they connect together and why they are relevant to this research study. The second half of this chapter now describes in detail how this methodological approach (the *what*) was deployed in the design of this research study (the *how*).

3.3 Research design

This section provides a description and rationale for the research design. A qualitative case study methodology forms the basis of this research. The case is now identified and described, followed by a detailed explanation of its design, which includes data collection, management, and analysis.

3.3.1 Defining the case

Defining the case is central to case study research, as it shapes the scope and focus of inquiry (Yin, 2018). This exploratory study investigates how Industry 5.0 is represented through the accreditation practices applied to engineering education in Ireland. The 'case' centres on Engineers Ireland, the professional body responsible for accrediting engineering programmes nationally, and focuses specifically on its role in accrediting one HEI. The case is bounded by three key parameters. First, the institutional setting - Engineers Ireland's accreditation of one HEI (undergoing accreditation for twenty-two engineering programmes). Second, the time frame - the accreditation of the HEI's programmes occurred within the first half of 2023. Finally, the regulatory framework - the application of the 2021 Engineers Ireland accreditation criteria (EIAC). This bounded case provided a focused lens to explore how accreditation practices contribute to the construction of Industry 5.0 within engineering education, particularly through the interpretation and enactment of the seven features of the Engineering Education 5.0 model.

3.3.1.1 Sampling strategy

Sampling refers to the process of selecting a subset from within a population (Creswell, 2012). In theory, it allows the researcher to present accurate findings from a population without collecting data from the entire population (Denscombe, 2010). The sampling approach for the case was purposive, as Engineers Ireland is the only accreditation body in Ireland that oversees, on the one hand, the accreditation of engineering programmes in Ireland, as well as the development of new accreditation criteria. Engineers Ireland is also a signatory to international agreements of mutual recognition.

3.3.1.2 Research Design

The case study was designed, conducted, and implemented across three concurrent phases: (i) interviews with members of Engineers Ireland's accreditation board, (ii) analysis of the 2021 EIAC document and (iii) analysis of the self-assessment reports (SARs) constructed throughout 2023. Each phase was designed to answer a specific sub-research question.

- *Through the lens of Engineering Education 5.0, how do members of the accreditation board of Engineers Ireland understand the current accreditation criteria? (Phase One)*
- *How is Engineering Education 5.0 represented in the 2021 Engineers Ireland Accreditation Criteria? (Phase Two)*
- *How is Engineering Education 5.0 represented in the programme outcomes in the self-assessment reports produced as part of accreditation in a HEI in Ireland? (Phase Three)*
- How is Engineering Education 5.0 represented in the programme outcomes in the self-assessment reports produced as part of accreditation in a HEI in Ireland?

Following the definition of the case, purposive decisions were made regarding participant selection and the identification of relevant documents. An important component of the sampling strategy involved the establishment of a non-disclosure agreement (NDA) between DCU and Engineers Ireland. This agreement enabled access to both interview participants as well as institutional documents produced by the HEI under investigation. The sampling strategies for each phase are detailed in sections 3.3.1.2.1-3.3.1.2.3 below.

3.3.1.2.1 Phase One

Interviews with members of the accreditation board of Engineers Ireland

The function of the accreditation board of Engineers Ireland is twofold: First, it is responsible for developing criteria for the Engineers Ireland accreditation document, a process which takes place approximately every 5-7 years. Second, they formally approve panel reports submitted after each accreditation visit. These dual roles position board members as key actors in the construction of accreditation practices, making them essential participants for this study. When vacancies arise, board members are appointed by the Executive Board of Engineers Ireland and typically bring a blend of academic and industry expertise, often with prior experience serving on accreditation panels. There are usually up to fifteen members on the board, and they are appointed due to their academic or industry experience and expertise in engineering education.

Phase One of the research involved semi-structured interviews with members of this board. A maximum variation sampling strategy was adopted to capture a diverse range of perspectives across professional roles, disciplinary backgrounds, career stages, and gender, thus ensuring that insights were not limited to any single viewpoint or institutional type. This purposive sampling approach ensured a heterogeneous sample that included a balance of academic and industry backgrounds, strategic and operational engagement with accreditation, and varying levels of seniority and experience, thus supporting the credibility and richness of the data collected.

A gatekeeper approach was taken to recruit participants. ,To ensure impartiality and minimise researcher influence, a representative of Engineers Ireland contacted the current board members on the researcher's behalf, distributing an information sheet outlining the study's aims, methods, and ethical safeguards. Five members expressed interest in participating. From these, three interviewees (I#1, I#2, and I#3) were selected to reflect the maximum variation strategy and offer a representative cross-section of the board's composition:

I#1 is a senior professional and was selected because of their extensive experience in both industry and academia. Their dual-sector perspective, coupled with long-standing involvement in accreditation activities, provided insight into how the EIAC is constructed, interpreted and operationalised across professional contexts. I#1 also contributed to previous EIAC development cycles.

I#2 is an academic leader based at a large university. As a relatively recent appointee to the board, I#2 contributed a fresh perspective on current accreditation practices and how newer board members engage with the EIAC framework. Their disciplinary expertise and institutional context also brought variation in the interpretation of accreditation criteria.

I#3 is a senior academic with deep involvement in the most recent revision of the EIAC. They were directly engaged in consultation processes and internal deliberations, offering detailed accounts of the rationale behind key changes to the accreditation criteria and the contested meanings of Industry 5.0 within those discussions.

3.3.1.2.2 Phase Two

Engineers Ireland accreditation criteria document

Phase Two comprised a document analysis of the latest EIAC (Engineers Ireland, 2021). It is a publicly available document and was sourced from the Engineers Ireland website. This document was selected as it provides the official framework against which engineering programmes are assessed and therefore offers critical insight into how educational standards and professional competencies are defined in the context of accreditation.

3.3.1.2.3 Phase Three

Self-assessment reports

Phase Three used convenience sampling to select the HEI, which was undergoing accreditation of its engineering programmes by Engineers Ireland during the timeframe bounded by the case. The accreditation process ensures that programmes meet both national and international standards for engineering education. The HEI produced SARs for programmes applying for accreditation. A SAR contains several sections relating to the organisation and resourcing of the programme, along with entry standards and details of modules included in the programme. It also provides detail on student progression, programme management and quality assurance processes. As illustrated in Table 3-2, the most important section of the SAR is the programme outcomes (PO) section, which articulates how a programme has achieved the eight mandatory POs; thus, the POs of each SAR were selected as the data to collect and analyse. As part of accreditation, the HEI must articulate their understanding of each PO and outline how it has influenced programme design. HEIs are expected to document how every programme element, such as modules, laboratory work, projects, and work placements, contributes to achieving the POs. Detailed explanations of relevant learning outcomes from various modules and learning experiences should support each PO. Therefore, a convenience sampling strategy for the SARs was also employed as they were accessible to the researcher.

Table 3-2: Structure of Self-assessment report (adapted from Engineers Ireland, (2023, p.6))

1	**Titles of programme(s) and education standard claimed**
	The HEI should specify which of the four educational standards it believes each of its programmes has achieved.
2	**Previous accreditation**
	For programmes that have previously been accredited, the HEI must describe how previous conditions have been implemented and/or recommendations have been considered.
3	**Organisation and resourcing of engineering education**
	Key personnel should be identified in the diagram so that Engineers Ireland and the visiting panels are clear about where responsibilities lie and who are the key contact points
4	**Programme educational objectives and viability**
	The HEI should describe the objectives of the programme in the context of the mission and strategy of the institution/department and the requirements of industry, students and the engineering profession
5	**Entry Standard, transfer and mobility requirements**
	The HEI should describe its ethos, policies and procedures in terms of the entry standard of students being admitted to Stage 1 of the programme.
6	**Programme duration, structure and module list**
	The HEI should describe its ethos, policies and procedures in terms of the entry standard of students being admitted to Stage 1 of the programme.
7	**Assessment of student performance**
	The HEI should describe its approach to the assessment of student performance so that the extent to which students achieve the learning outcomes underpinning the Programme Outcomes can be assessed.
8	**Titles of final-year projects**
	The HEI should provide a list consisting of the titles of all final year/capstone projects carried out by graduates in at least one graduating year immediately prior to the date of the submission of the selfassessment report.
9	**Statistics of student progression and performance in examinations**
	Tables showing the student progression
10	**Programme management and development**
	Tables showing the student progression
11	**Quality assurance processes**
	The HEI should indicate how QA is achieved by describing, in concise format, how such processes operate in the context of the programmes for accreditation.
12	**Summary of graduate and employer surveys**
	The opinions of graduates and employers should be included
13	**Analysis and achievement of Programme Outcomes**
	This is the most important section of the self-assessment report. The HEI should provide a detailed explanation of its understanding of each Programme Outcome and should also be able to demonstrate how each programme's design has been influenced by the Programme Outcomes. Engineers Ireland will not restrict the HEI to a pro-forma response.

Taken together, all the phases worked to provide the dataset for this research study and answer the research questions.

3.3.1.3 Analytical Framework: Ball's (1993) policy cycle

Ball's (1993) policy cycle provided the overarching analytical framework for this study. Consistent with a social constructionist orientation, the framework views policy as discursively produced and enacted through situated practices, rather than as a linear or technical instrument. Its three interrelated contexts, influence, text production, and practice, offered a structured lens through which to design the case and interpret the data. Each phase of the study, which corresponds to a sub-research question, was aligned with one of these contexts: interviews with accreditation board members (Phase One - context of influence), analysis of the 2021 Engineers Ireland Accreditation

Criteria (Phase Two - context of text production), and institutional self-assessment reports (Phase Three - context of practice). Using Ball's framework in this way enabled a systematic interrogation of how Industry 5.0 is constructed across different sites of policy activity, while also making visible the interpretive negotiations and institutional dynamics that shape accreditation practices.

3.3.2 Data collection/generation

This section describes the scale, range and extent of data collected during the research study, including researcher-generated, publicly available, and HEI-generated documents. The design method for collecting each type is now discussed.

3.3.2.1 Interview transcripts (Phase One)

The first set of data generated was from interview transcripts. Three in-depth semi-structured interviews were conducted with members of the accreditation board of Engineers Ireland. The interviews aimed to understand the views and experiences of members of the accreditation board of the accreditation process, the updated criteria and the features of Engineering Education 5.0. Specifically, the interviews explored how board members interpret the evolving demands of engineering education and how these are reflected in accreditation practices. A detailed interview schedule was devised and prompts and probes were prepared for the semi-structured interviews (Appendix B). Interviews were conducted online using the researcher's DCU Zoom account, which is password-protected. The interviews lasted approximately forty-five minutes each. While audio and video were used for the Zoom interviews, only the audio recordings were saved. Once transcribed the audio files were deleted with the transcriptions stored securely in a password-protected cloud folder ready for analysis.

3.3.2.2 Publicly available document (Phase Two)

This document is the latest version of the EIAC [13], published in January 2021. The EIAC was produced by Engineers Ireland's accreditation board, reflecting the professional body's role in codifying national standards and values for engineering education. It contains the Programmes Outcomes (POs) and Programme Areas (PAs) for each of the categories of professional title. The EIAC document was sourced and downloaded from the Engineers Ireland website and stored for analysis.

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[13] https://www.engineersireland.ie/listings/resource/519

3.3.2.3 User generated documents (Phase Three)

The SARs were produced by the HEI as part of the accreditation of their engineering programmes in 2023. They were constructed by staff from the various programmes in the university according to the 2021 version of the EIAC. Once the NDA was secured, Engineers Ireland provided the researcher with access to a secure server. In total, eleven SARs were collected. The documents were subsequently downloaded and stored on the secure DCU Google Drive for analysis.

3.3.3 Data management

The data collected for this research were stored securely in the researcher's cloud password-protected folder on her DCU Google Drive. Following the recommendations of Denzin and Lincoln (2011), the data generated was organised and stored in a way that enabled easy coding and retrieval for analysis. Folders were created for each phase. Within each folder, sub-folders were created to store sets of data related to specific parts of the research question. The interviews were transcribed, checked for accuracy and stored in a dedicated folder. The EIAC was downloaded in PDF format and stored on the researcher's Google Drive. The eleven SARs were deconstructed and reorganised to extract the mandatory POs, previously identified as the most critical component of the SARs. Several considerations concerning the treatment of this content are summarised in Table 3-3.

Across the eleven SARs, twenty-two programmes were identified as having been submitted for (re)accreditation, spanning NFQ levels 6 to 9. Each programme's NFQ level, title, and accreditation status (first-time or re-accreditation) is presented in the table. Sixteen documents were ultimately reconstructed and analysed for two reasons:

- No standalone programmes at NFQ Level 6 were submitted for (re)accreditation. However, six SARs (1, 2, 4, 8, 9, and 10) included NFQ Level 7 programmes with embedded Level 6 awards.
- SAR 4 contained details for six programmes across multiple engineering disciplines and accreditation statuses, all within a single report.

Table 3-3: Relationship between Self-Assessment Reports and documents for analysis

SAR #	Programme #	NFQ	Initials	Educational standard	Accreditation sought	Document #
1	1	7	BEng	Associate Engineer	Re accreditation	1
1	2	6	HC	Engineering Technician	Re accreditation	1
2	3	8	BEng (Hons)	Chartered Engineer with FL	Re accreditation	2
2	4	9	MEng	Chartered Engineer	First time	3
3	5	8	BEng (Hons)	Chartered Engineer with FL	Re accreditation	4
4	6	7	BEng	Associate Engineer	Re accreditation	5
4	7	6	HC	Engineering Technician	Re accreditation	5
4	8	7	BEng	Associate Engineer	First time	5
4	9	8	BEng (Hons)	Chartered Engineer with FL	Re accreditation	6
4	10	9	MEng	Chartered Engineer	Re accreditation	7
4	11	9	MEng	Chartered Engineer	Re accreditation	8
5	12	6	HC	Engineering Technician	Re accreditation	9
5	13	7	BEng	Associate Engineer	Re accreditation	9
6	14	8	BEng (Hons)	Chartered Engineer with FL	First time	10
7	15	8	BEng (Hons)	Chartered Engineer with FL	First time	11
8	16	7	BEng	Associate Engineer	Re accreditation	12
8	17	6	HC	Engineering Technician	Re accreditation	12
9	18	8	BEng (Hons)	Chartered Engineer with FL	Re accreditation	13
9	19	9	MEng	Chartered Engineer	First time	14
10	20	7	BEng	Associate Engineer	Re accreditation	15
10	21	6	HC	Engineering Technician	Re accreditation	15
11	22	8	BEng (Hons)	Chartered Engineer with FL	First time	16

The corpus of data collected was then uploaded to NVivo for analysis.

3.4 Data analysis process

This section outlines the analytical approach applied to both collected and generated data. Braun and Clarke's (2020) RTA was used to analyse all three data sets. After initial data management and familiarisation, coding focused primarily on identifying and labelling features of the Engineering Education 5.0 model. Patterns and connections within the coded data informed the generation of initial themes, which were then revisited and refined to ensure they were well-supported by the data and addressed the research question meaningfully.

Rather than proceeding linearly or being driven solely by theory, the analysis involved a recursive, iterative dialogue between data and theory. This process, and the strategies used to enhance the trustworthiness of the findings: credibility, transferability, dependability, and confirmability, are further detailed below and in a later section of this chapter.

3.4.1 Reflexive thematic analysis of the dataset

NVivo software was used to support the RTA process, serving as an audit trail for coding, category development, and theme refinement. The analysis was extensive and iterative, involving multiple cycles of revision, with each adjustment grounded in a clear analytical rationale. In line with Braun and Clarke (2019) guidance, the six phases of RTA were treated not as linear steps but as overlapping and interconnected. Each phase is outlined below, with specific implementation examples drawn from each dataset. Furthermore, although each phase was analysed as a single entity, the same approach was adopted.

3.4.1.1 Step One: data familiarisation

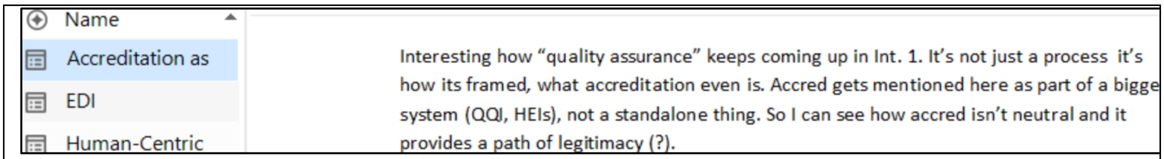
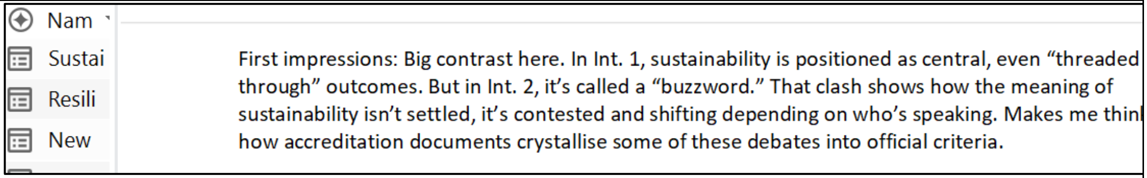
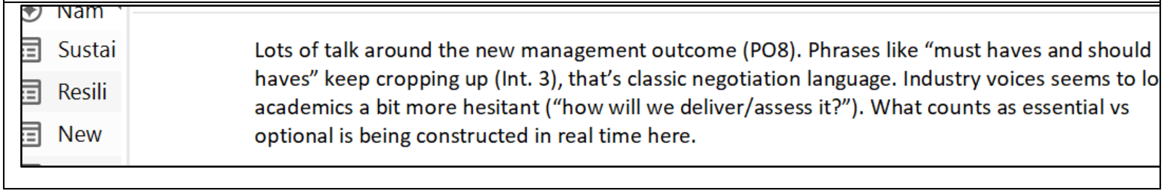
The first step of RTA involved deep immersion in the dataset to become intimately familiar with its content and context (Braun and Clarke, 2006, 2019). This stage was foundational for identifying initial patterns of meaning that would later inform coding and theme development. Taking each dataset:

3.4.1.1.1 Phase One (the Interviews)

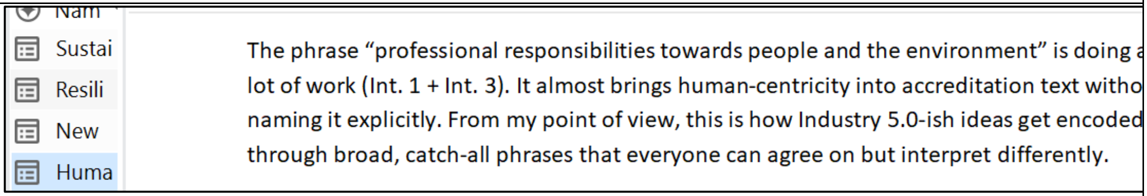
The three interviews were audio-recorded and subsequently transcribed verbatim. These transcripts were then imported into NVivo, which served as the primary workspace for managing and analysing the data. The familiarisation process involved reading and rereading the transcripts to become immersed in the interviewees' accounts. This iterative engagement enabled an initial sense of the tone, language, and emphasis within each interview, which offered early cues to meaning.

For example, as part of this process, initial insights were captured in the form of reflexive notes within NVivo using the memo function. These memos recorded emerging thoughts, questions, and associations while engaging with the raw data, providing a transparent audit trail of how meanings were beginning to be constructed. Examples are illustrated in Table 3-4 below.

Table 3-4: Step One. Examples of reflexive memos from Phase One (interviews)

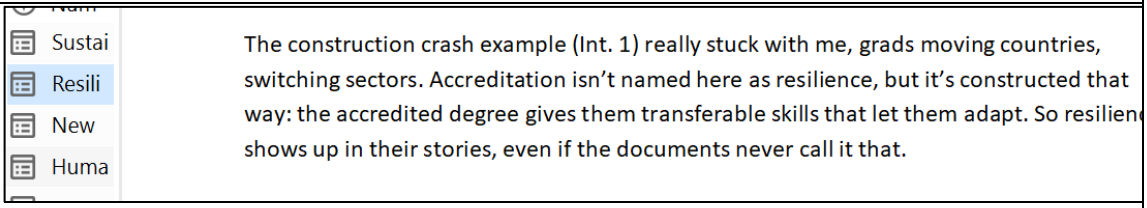
 Interesting how "quality assurance" keeps coming up in Int. 1. It's not just a process it's how its framed, what accreditation even is. Accred gets mentioned here as part of a bigge system (QQI, HEIs), not a standalone thing. So I can see how accred isn't neutral and it provides a path of legitimacy (?).
This example illustrates familiarisation by noticing how recurring language constructs accreditation's meaning, while reflexively acknowledging the researcher's interest in legitimacy discourses.
 First impressions: Big contrast here. In Int. 1, sustainability is positioned as central, even "threaded through" outcomes. But in Int. 2, it's called a "buzzword." That clash shows how the meaning of sustainability isn't settled, it's contested and shifting depending on who's speaking. Makes me thin how accreditation documents crystallise some of these debates into official criteria.
This shows early sensitivity to divergent framings, reflecting how familiarisation involves recognising contested discourses rather than seeking fixed definitions.
 Lots of talk around the new management outcome (PO8). Phrases like "must haves and should haves" keep cropping up (Int. 3), that's classic negotiation language. Industry voices seems to lo academics a bit more hesitant ("how will we deliver/assess it?"). What counts as essential vs optional is being constructed in real time here.

Here, Stage 1 notes capture the negotiation of meaning in participants' words, with reflexive awareness that my reading is shaped by attention to power and policy processes.



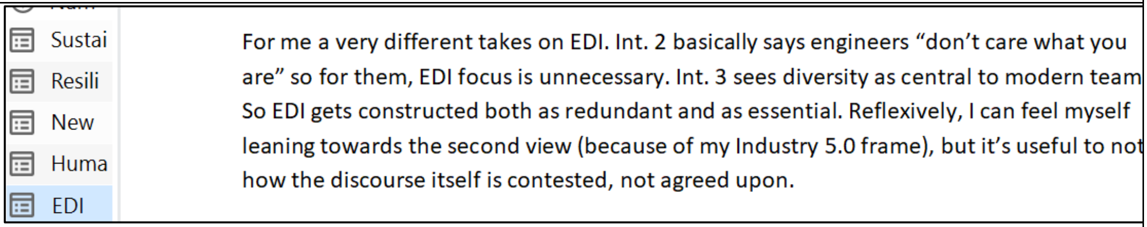
The phrase "professional responsibilities towards people and the environment" is doing lot of work (Int. 1 + Int. 3). It almost brings human-centricity into accreditation text witho naming it explicitly. From my point of view, this is how Industry 5.0-ish ideas get encoded through broad, catch-all phrases that everyone can agree on but interpret differently.

This demonstrates familiarisation as an interpretive process, while reflexively recognising that the Industry 5.0 lens positions the analysis to interpret this as encoding human-centricity.



The construction crash example (Int. 1) really stuck with me, grads moving countries, switching sectors. Accreditation isn't named here as resilience, but it's constructed that way: the accredited degree gives them transferable skills that let them adapt. So resilien shows up in their stories, even if the documents never call it that.

This illustrates how familiarisation involves identifying implicit meanings, while reflexively recognising that the analytical lens connects these accounts to the resilience pillar of Industry 5.0.



For me a very different takes on EDI. Int. 2 basically says engineers "don't care what you are" so for them, EDI focus is unnecessary. Int. 3 sees diversity as central to modern team So EDI gets constructed both as redundant and as essential. Reflexively, I can feel myself leaning towards the second view (because of my Industry 5.0 frame), but it's useful to not how the discourse itself is contested, not agreed upon.

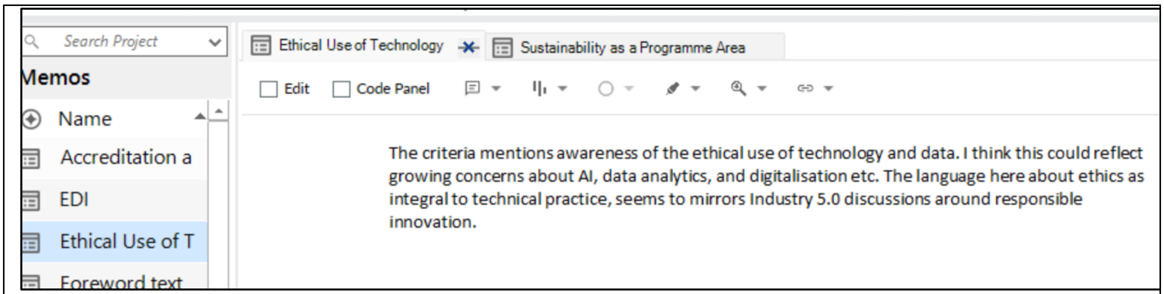
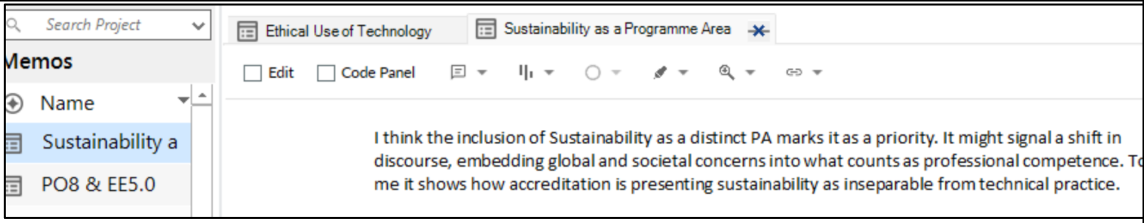
This highlights how Stage 1 requires documenting differences in meaning, while reflexively acknowledging that the researcher's interpretive stance shapes how such contrasts are understood.

In this way, the process of data familiarisation went beyond surface-level reading to engage with how meanings are negotiated, contested, and constructed within the interviews. The use of memos ensured that early impressions, questions, and interpretive possibilities were systematically documented and remained visible throughout subsequent stages of the analysis.

3.4.1.1.2 Phase Two (the EIAC)

During familiarisation, the EIAC was read and reread with attention to how meaning was constructed through its language and organisation. Examples of memos shown in Table 3-5 observed how the criteria around the ethical use of technology and data reflect growing societal concerns about AI, analytics, and digitalisation and highlighted the inclusion of Sustainability as a distinct Programme Area, which signals a shift in accreditation priorities.

Table 3-5: Step One. Examples of reflexive memos from Phase Two (Engineers Ireland Accreditation Criteria)

 The criteria mentions awareness of the ethical use of technology and data. I think this could reflect growing concerns about AI, data analytics, and digitalisation etc. The language here about ethics as integral to technical practice, seems to mirrors Industry 5.0 discussions around responsible innovation.
This phrasing constructs ethics as inseparable from technical practice, echoing broader Industry 5.0 discourses on responsible innovation.
 I think the inclusion of Sustainability as a distinct PA marks it as a priority. It might signal a shift in discourse, embedding global and societal concerns into what counts as professional competence. T me it shows how accreditation is presenting sustainability as inseparable from technical practice.
Here sustainability is not treated as an external consideration but constructed as integral to professional competence, embedding global and societal concerns within the very definition of engineering education.

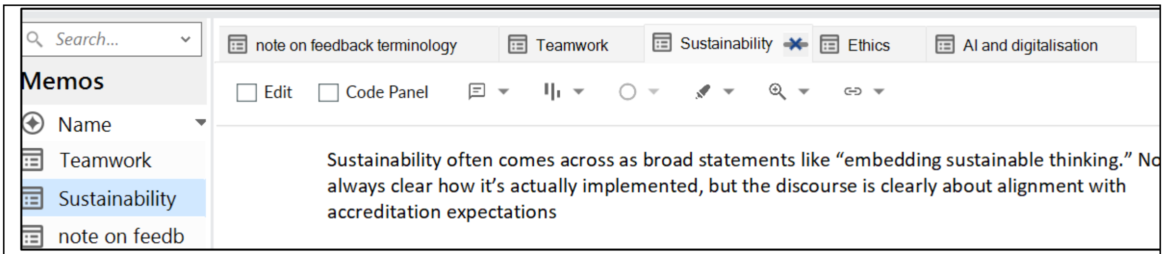
These reflections illustrate how the familiarisation process went beyond surface-level reading to recognise the discursive framing of values and priorities within the EIAC. Reflexively, it is acknowledged by the researcher that the Industry 5.0 lens guiding this study shaped the aspects of the text that were most salient during familiarisation.

3.4.1.1.3 Phase Three: (the POs of the SARs)

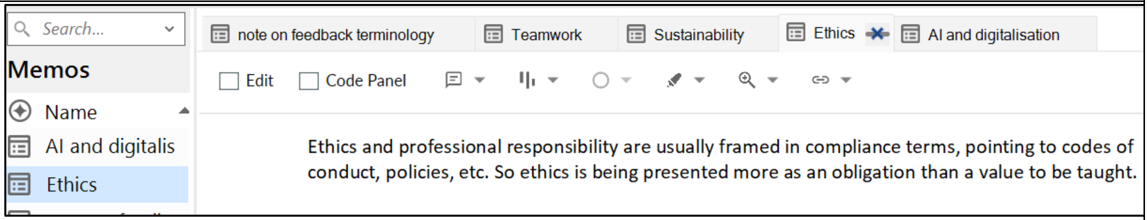
Each of the PO sections of the 16 SARs was reviewed both individually and collectively to build familiarity with how programme teams framed their compliance with the accreditation criteria. This process involved repeated readings of the documents to identify recurring emphases, points of alignment with the EIAC, and areas of divergence. The familiarisation stage was not limited to noting surface-level content but focused on how meaning was constructed through the ways programme teams narrated their teaching, assessment, and graduate attributes.

Reflective memos were used throughout this stage to capture initial insights, questions, and associations. These notes recorded how particular discursive strategies were deployed in the POs of the SARs and how they related to broader accreditation priorities, as shown in Table 3-6.

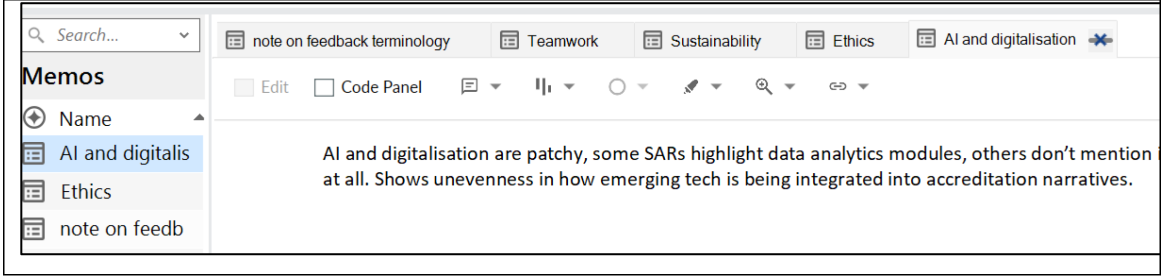
Table 3-6: Step One. Reflexive memos from Phase Three (the Programme Outcomes of the Self-Assessment Reports)



Sustainability often comes across as broad statements like "embedding sustainable thinking." No always clear how it's actually implemented, but the discourse is clearly about alignment with accreditation expectations



Ethics and professional responsibility are usually framed in compliance terms, pointing to codes of conduct, policies, etc. So ethics is being presented more as an obligation than a value to be taught.



AI and digitalisation are patchy, some SARs highlight data analytics modules, others don't mention at all. Shows unevenness in how emerging tech is being integrated into accreditation narratives.

These memos illustrate how the familiarisation process involved recognising both consistencies and anomalies across the POs in the SARs. Some themes, such as teamwork, were consistently emphasised, while others, such as digitalisation, showed considerable variation. In this way, familiarisation with the POs of the SARs created an initial idea of how programmes position themselves within the accreditation process, providing early insights that informed the development of subsequent coding.

Therefore, across all three data sources, Stage 1 familiarisation involved more than simply reading the texts (Braun and Clarke, 2019). It required close attention to the language, tone, and structure of the material, and reflexive memo writing captured early impressions and questions. This stage laid the groundwork for subsequent coding by documenting how meanings were being negotiated, contested, and constructed in interviews, accreditation criteria, and the POs of the SARs.

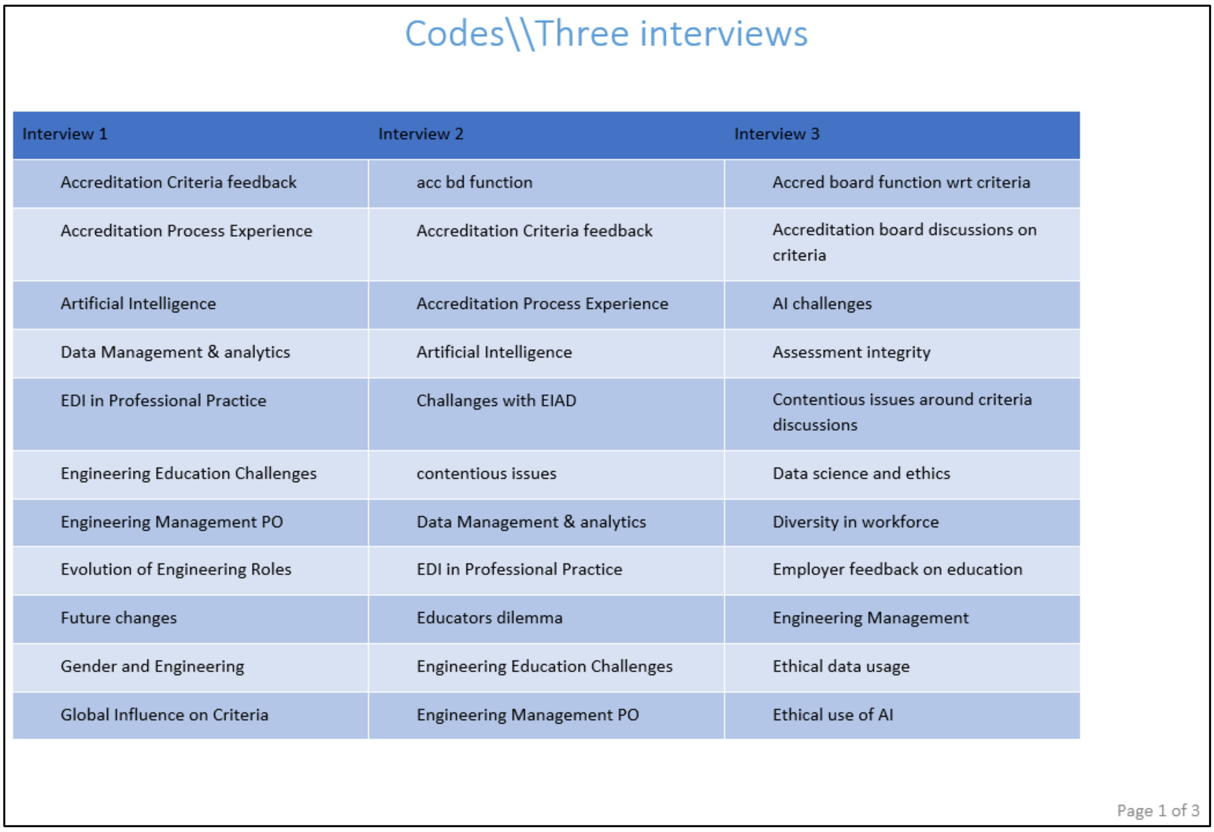
3.4.1.2 Step Two: generating initial codes

This phase focused on systematically identifying and tagging meaningful features of the data. These initial codes formed the foundation for theme development (Braun and Clarke, 2020). Coding was informed by the research questions and guided by the seven features of Engineering Education 5.0, as introduced in Chapter Two. That is, the descriptive codes generated identified specific aspects of the data that aligned with each of the seven features of Engineering Education 5.0. At this step, they were essentially labels identifying these features within the data.

3.4.1.2.1 Phase One (the Interviews)

The interview transcripts were coded line-by-line using NVivo with attention to both explicit statements and underlying meanings. Initial codes captured perceptions of alignment with Engineering Education 5.0, with examples from the Nvivo codebook as shown in Table 3-7. Each column represents one interview transcript, and examples of topics identified during line-by-line coding in NVivo.

Table 3-7: Step Two. Phase One (interviews). Examples from the Nvivo codebook



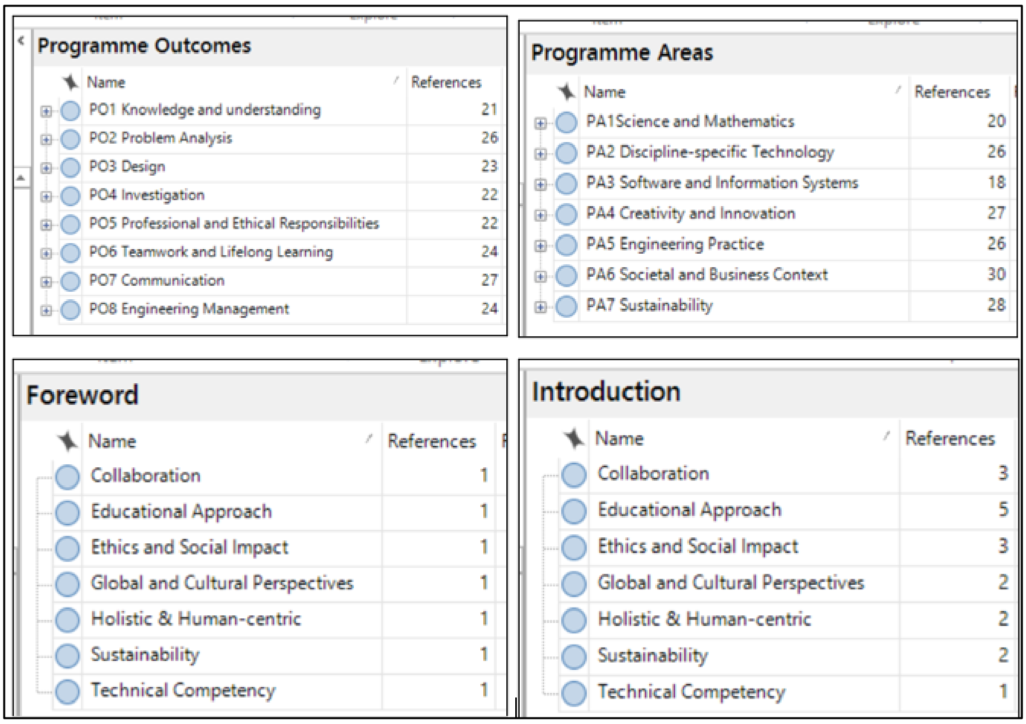
Codes\\Three interviews

Interview 1	Interview 2	Interview 3
Accreditation Criteria feedback	acc bd function	Accred board function wrt criteria
Accreditation Process Experience	Accreditation Criteria feedback	Accreditation board discussions on criteria
Artificial Intelligence	Accreditation Process Experience	AI challenges
Data Management & analytics	Artificial Intelligence	Assessment integrity
EDI in Professional Practice	Challanges with EIAD	Contentious issues around criteria discussions
Engineering Education Challenges	contentious issues	Data science and ethics
Engineering Management PO	Data Management & analytics	Diversity in workforce
Evolution of Engineering Roles	EDI in Professional Practice	Employer feedback on education
Future changes	Educators dilemma	Engineering Management
Gender and Engineering	Engineering Education Challenges	Ethical data usage
Global Influence on Criteria	Engineering Management PO	Ethical use of AI

Page 1 of 3

3.4.1.2.2 Phase Two (the EIAC)

The EIAC was coded with a focus on identifying text associated with the seven Engineering Education 5.0 features. Codes were generated around concepts such as knowledge, ethics, sustainability, and design. This began with the text of the *Foreword* and *Introduction* sections and then proceeded to the description of each *Programme Outcome* and *Programme Area*. Examples of this process are shown in Figure 3-1.



Programme Outcomes

Name	References
PO1 Knowledge and understanding	21
PO2 Problem Analysis	26
PO3 Design	23
PO4 Investigation	22
PO5 Professional and Ethical Responsibilities	22
PO6 Teamwork and Lifelong Learning	24
PO7 Communication	27
PO8 Engineering Management	24

Programme Areas

Name	References
PA1Science and Mathematics	20
PA2 Discipline-specific Technology	26
PA3 Software and Information Systems	18
PA4 Creativity and Innovation	27
PA5 Engineering Practice	26
PA6 Societal and Business Context	30
PA7 Sustainability	28

Foreword

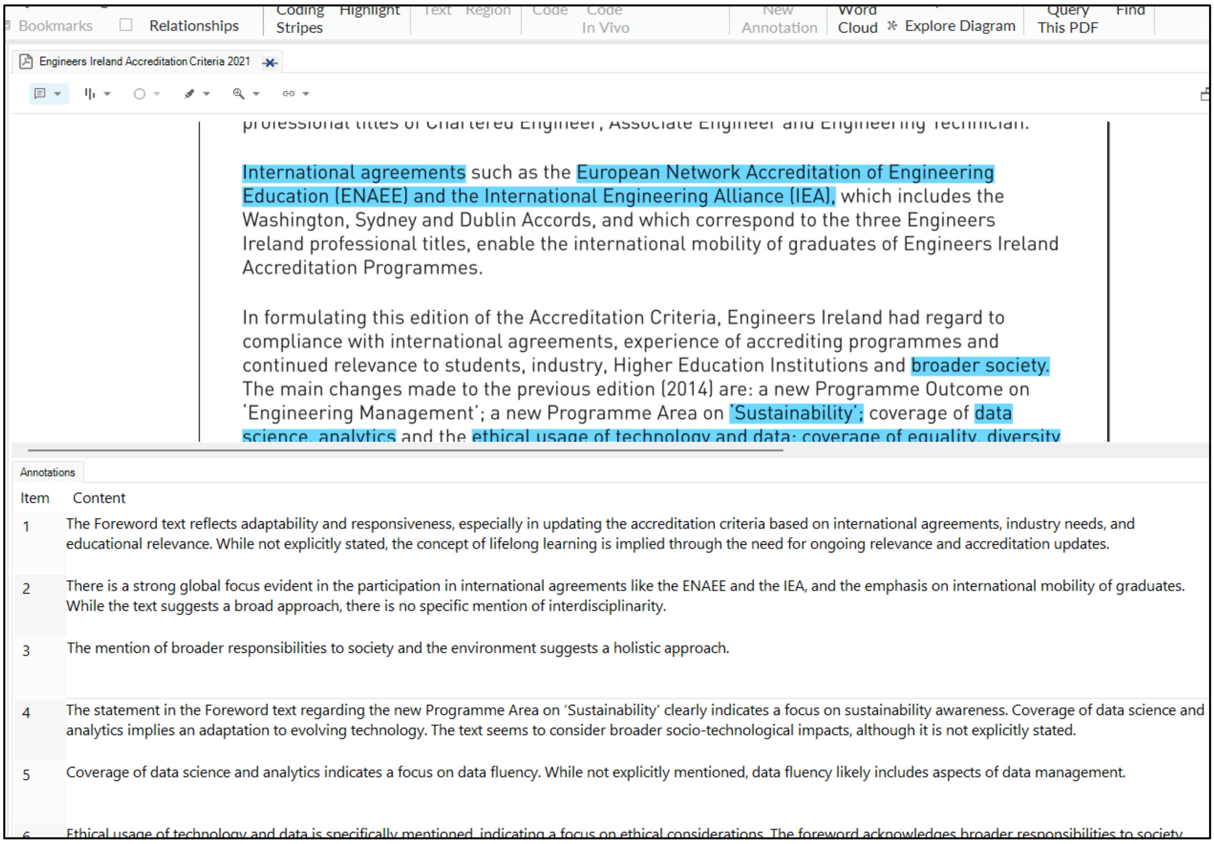
Name	References
Collaboration	1
Educational Approach	1
Ethics and Social Impact	1
Global and Cultural Perspectives	1
Holistic & Human-centric	1
Sustainability	1
Technical Competency	1

Introduction

Name	References
Collaboration	3
Educational Approach	5
Ethics and Social Impact	3
Global and Cultural Perspectives	2
Holistic & Human-centric	2
Sustainability	2
Technical Competency	1

Figure 3-1: Step Two. Examples of initial coding process for Phase Two (the EIAC)

Where the researcher interpreted a connection between the features of Engineering Education 5.0 and the text in the Foreword and Introduction sections of the EIAC, a note of analysis or implication, in the form of an annotation, was added in Nvivo, as shown in Figure 3-2.



professional titles of Chartered Engineer, Associate Engineer and Engineering Technician.

International agreements such as the European Network Accreditation of Engineering Education (ENAEE) and the International Engineering Alliance (IEA), which includes the Washington, Sydney and Dublin Accords, and which correspond to the three Engineers Ireland professional titles, enable the international mobility of graduates of Engineers Ireland Accreditation Programmes.

In formulating this edition of the Accreditation Criteria, Engineers Ireland had regard to compliance with international agreements, experience of accrediting programmes and continued relevance to students, industry, Higher Education Institutions and broader society. The main changes made to the previous edition (2014) are: a new Programme Outcome on 'Engineering Management'; a new Programme Area on 'Sustainability'; coverage of data science, analytics and the ethical usage of technology and data; coverage of equality, diversity

Item	Content
1	The Foreword text reflects adaptability and responsiveness, especially in updating the accreditation criteria based on international agreements, industry needs, and educational relevance. While not explicitly stated, the concept of lifelong learning is implied through the need for ongoing relevance and accreditation updates.
2	There is a strong global focus evident in the participation in international agreements like the ENAEE and the IEA, and the emphasis on international mobility of graduates. While the text suggests a broad approach, there is no specific mention of interdisciplinarity.
3	The mention of broader responsibilities to society and the environment suggests a holistic approach.
4	The statement in the Foreword text regarding the new Programme Area on 'Sustainability' clearly indicates a focus on sustainability awareness. Coverage of data science and analytics implies an adaptation to evolving technology. The text seems to consider broader socio-technological impacts, although it is not explicitly stated.
5	Coverage of data science and analytics indicates a focus on data fluency. While not explicitly mentioned, data fluency likely includes aspects of data management.
6	Ethical usage of technology and data is specifically mentioned, indicating a focus on ethical considerations. The foreword acknowledges broader responsibilities to society

Figure 3-2: Step Two. Examples of reflexive notes made during initial coding stage for Phase Two (the EIAC)

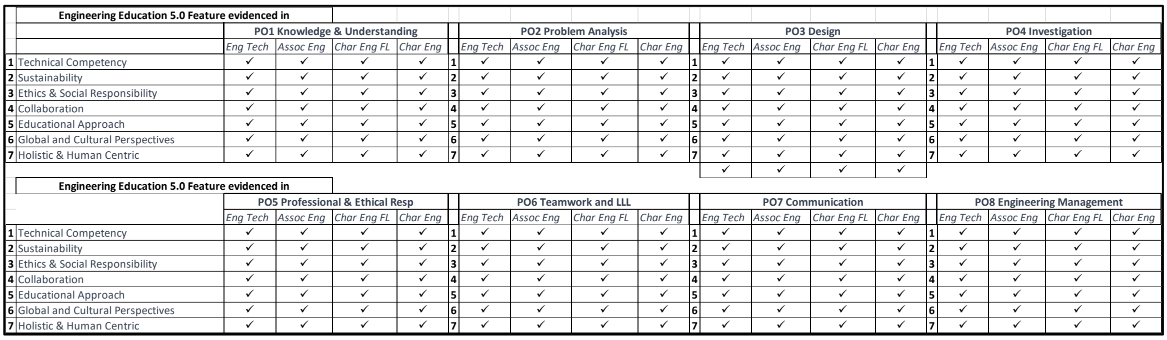
Following the completion of the above process, a tracking matrix was compiled, which allowed the researcher to ensure the complete mapping of each Engineering Education 5.0 feature, as demonstrated for the *Foreword* and *Introduction* text in Table 3-8. Once the analysis of each feature was complete, a tick was placed in the box as a visual tool for the researcher (Table 3-8). The data extracts for each feature were stored in sub-folders in Nvivo for further analysis.

Table 3-8: Step Two. Matrix for Phase Two tracking analysis of Foreword & Introduction text of the EIAC

	Engineering Education 5.0 feature analysed in		
		Foreward	**Introduction**
1	Technical Competency	✓	✓
2	Sustainability	✓	✓
3	Ethics and Social Impact	✓	✓
4	Collaboration	✓	✓
5	Educational Approach	✓	✓
6	Global and Cultural Perspectives	✓	✓
7	Holistic & Human-centric	✓	✓

The same process was followed for the initial coding of the PO and PA sections of the EIAC. However, the process was more complex for the POs due to the four education levels associated with different professional titles, as laid down by Engineers Ireland, namely, Engineering Technician, Associate Engineer, Chartered Engineer with Further Learning and Chartered Engineer. However, once the matrix was constructed, which took the four levels into account along with the eight POs and the seven Engineering Education 5.0 features, the same procedure as the previous section was followed (Table 3-9).

Table 3-9: Step Two. Phase Two (a tracking matrix for the POs in the EIAC)

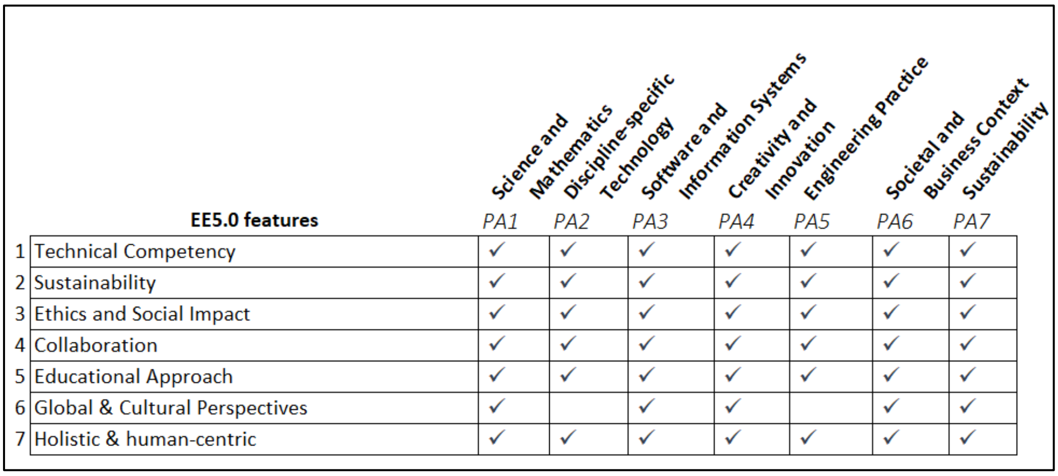


	Engineering Education 5.0 Feature evidenced in																			
		PO1 Knowledge & Understanding					**PO2 Problem Analysis**					**PO3 Design**					**PO4 Investigation**			
		Eng Tech	*Assoc Eng*	*Char Eng FL*	*Char Eng*		*Eng Tech*	*Assoc Eng*	*Char Eng FL*	*Char Eng*		*Eng Tech*	*Assoc Eng*	*Char Eng FL*	*Char Eng*		*Eng Tech*	*Assoc Eng*	*Char Eng FL*	*Char Eng*
1	Technical Competency	✓	✓	✓	✓	**1**	✓	✓	✓	✓	**1**	✓	✓	✓	✓	**1**	✓	✓	✓	✓
2	Sustainability	✓	✓	✓	✓	**2**	✓	✓	✓	✓	**2**	✓	✓	✓	✓	**2**	✓	✓	✓	✓
3	Ethics & Social Responsibility	✓	✓	✓	✓	**3**	✓	✓	✓	✓	**3**	✓	✓	✓	✓	**3**	✓	✓	✓	✓
4	Collaboration	✓	✓	✓	✓	**4**	✓	✓	✓	✓	**4**	✓	✓	✓	✓	**4**	✓	✓	✓	✓
5	Educational Approach	✓	✓	✓	✓	**5**	✓	✓	✓	✓	**5**	✓	✓	✓	✓	**5**	✓	✓	✓	✓
6	Global and Cultural Perspectives	✓	✓	✓	✓	**6**	✓	✓	✓	✓	**6**	✓	✓	✓	✓	**6**	✓	✓	✓	✓
7	Holistic & Human Centric	✓	✓	✓	✓	**7**	✓	✓	✓	✓	**7**	✓	✓	✓	✓	**7**	✓	✓	✓	✓
												✓	✓	✓	✓					

	Engineering Education 5.0 Feature evidenced in																			
		PO5 Professional & Ethical Resp					**PO6 Teamwork and LLL**					**PO7 Communication**					**PO8 Engineering Management**			
		Eng Tech	*Assoc Eng*	*Char Eng FL*	*Char Eng*		*Eng Tech*	*Assoc Eng*	*Char Eng FL*	*Char Eng*		*Eng Tech*	*Assoc Eng*	*Char Eng FL*	*Char Eng*		*Eng Tech*	*Assoc Eng*	*Char Eng FL*	*Char Eng*
1	Technical Competency	✓	✓	✓	✓	**1**	✓	✓	✓	✓	**1**	✓	✓	✓	✓	**1**	✓	✓	✓	✓
2	Sustainability	✓	✓	✓	✓	**2**	✓	✓	✓	✓	**2**	✓	✓	✓	✓	**2**	✓	✓	✓	✓
3	Ethics & Social Responsibility	✓	✓	✓	✓	**3**	✓	✓	✓	✓	**3**	✓	✓	✓	✓	**3**	✓	✓	✓	✓
4	Collaboration	✓	✓	✓	✓	**4**	✓	✓	✓	✓	**4**	✓	✓	✓	✓	**4**	✓	✓	✓	✓
5	Educational Approach	✓	✓	✓	✓	**5**	✓	✓	✓	✓	**5**	✓	✓	✓	✓	**5**	✓	✓	✓	✓
6	Global and Cultural Perspectives	✓	✓	✓	✓	**6**	✓	✓	✓	✓	**6**	✓	✓	✓	✓	**6**	✓	✓	✓	✓
7	Holistic & Human Centric	✓	✓	✓	✓	**7**	✓	✓	✓	✓	**7**	✓	✓	✓	✓	**7**	✓	✓	✓	✓

Again, following the same systematic approach, the seven PAs from the EIAC were analysed as reflected in the matrix in Table 3-10.

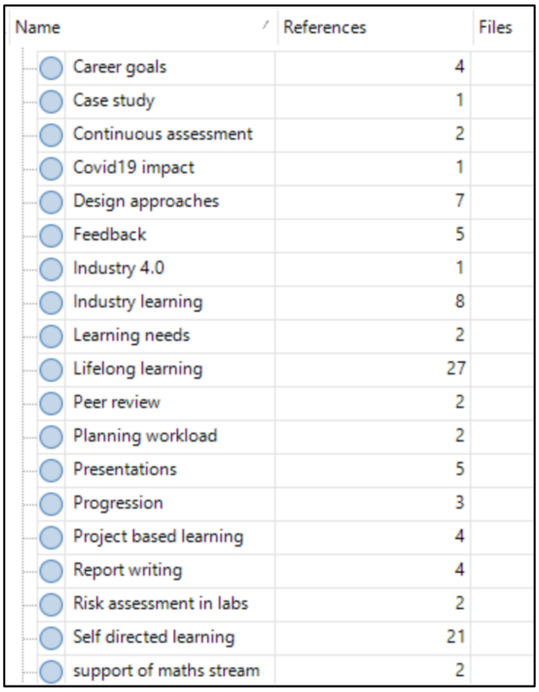
Table 3-10: Step Two. Matrix Phase Two tracking analysis (Programme Areas in the EIAC)



	EE5.0 features	Science and Mathematics PA1	Discipline-specific Technology PA2	Software and Information Systems PA3	Creativity and Innovation PA4	Engineering Practice PA5	Societal and Business Context PA6	Sustainability PA7
1	Technical Competency	✓	✓	✓	✓	✓	✓	✓
2	Sustainability	✓	✓	✓	✓	✓	✓	✓
3	Ethics and Social Impact	✓	✓	✓	✓	✓	✓	✓
4	Collaboration	✓	✓	✓	✓	✓	✓	✓
5	Educational Approach	✓	✓	✓	✓	✓	✓	✓
6	Global & Cultural Perspectives	✓		✓	✓		✓	✓
7	Holistic & human-centric	✓	✓	✓	✓	✓	✓	✓

3.4.1.2.3 *Phase Three: (the POs of the SARs)*

The SARs were also initially coded using Nvivo, where initial codes were generated. Given the variability in structure, coding remained flexible and iterative. Evidence of initial codes was documented in Nvivo, as shown in Figure 3-3.



Name	References	Files
Career goals	4	
Case study	1	
Continuous assessment	2	
Covid19 impact	1	
Design approaches	7	
Feedback	5	
Industry 4.0	1	
Industry learning	8	
Learning needs	2	
Lifelong learning	27	
Peer review	2	
Planning workload	2	
Presentations	5	
Progression	3	
Project based learning	4	
Report writing	4	
Risk assessment in labs	2	
Self directed learning	21	
support of maths stream	2	

Figure 3-3: Step Two. Initial codes for Phase Three (POs in Self-Assessment Reports)

Overall, across the three datasets, the codes captured both common and contested understandings of elements of Engineering Education 5.0 and accreditation, forming the analytic foundation for constructing themes in the following step.

3.4.1.3 Step Three: generating initial themes

In Step Three, the focus shifted from generating individual codes to identifying patterns and connections within the coded data. and developing initial themes, (Braun and Clarke, 2006, 2019). Themes are not simply groups of codes but are interpretive constructs developed by the researcher to make sense of complex and multifaceted data. It involved synthesising the codes to uncover deeper meanings and insights beyond the surface level. Codes were reviewed and collated into candidate themes. The process was iterative and supported by thematic maps and memos, with alignment to the Engineering Education 5.0 model. Taking each data set:

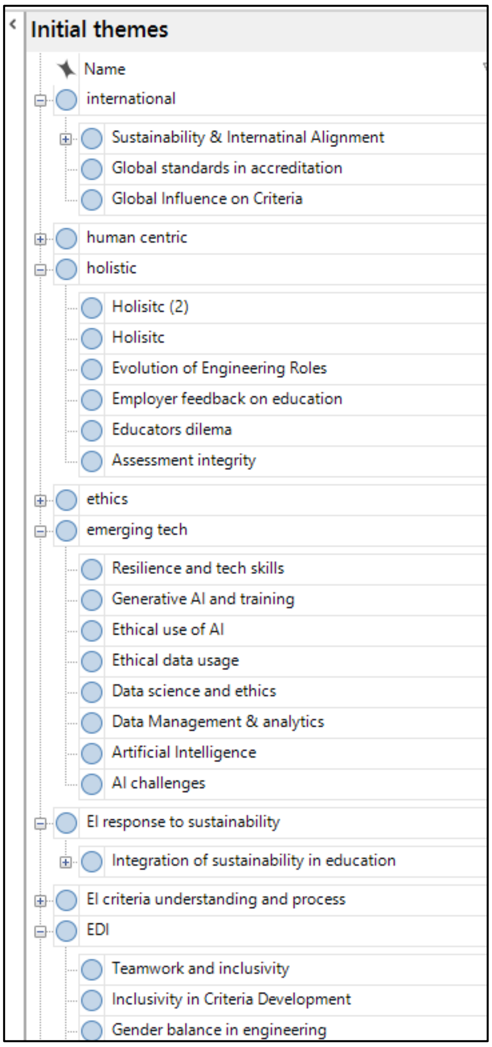
3.4.1.3.1 Phase One (the Interviews)

In the interview transcripts, themes began to take shape around participants' interpretations of the various features of Engineering Education 5.0. Each theme (such as *international*, *holistic*, *emerging tech*) is composed of sub-codes that share a conceptual relationship, as shown in Figure 3-4.

Name
○ CPD LLL
○ culture
○ Design
○ EDI
○ EI criteria understanding and process
○ EI response to sustainability
○ emerging tech
○ ethics
○ holistic
○ human centric
○ international
○ Perspectives on sustainability
○ quality
○ socail responsibility
○ Sustainability

Figure 3-4: Step Three. Generating initial themes from Phase One (the interviews)

Codes that reflected similar underlying ideas were clustered and refined into broader thematic categories. Figure 3-5 illustrates a selection of these initial themes derived from the interview transcripts. Then, discrete codes such as *Global Influence on Criteria*, *Artificial Intelligence*, and *Integration of Sustainability in Education* were grouped into more overarching themes, reflecting both the diversity and convergence of participant perspectives on the accreditation landscape.



Initial themes

Name

- international
  - Sustainability & Internatinal Alignment
  - Global standards in accreditation
  - Global Influence on Criteria
- human centric
- holistic
  - Holisitc (2)
  - Holisitc
  - Evolution of Engineering Roles
  - Employer feedback on education
  - Educators dilema
  - Assessment integrity
- ethics
- emerging tech
  - Resilience and tech skills
  - Generative AI and training
  - Ethical use of AI
  - Ethical data usage
  - Data science and ethics
  - Data Management & analytics
  - Artificial Intelligence
  - AI challenges
- EI response to sustainability
  - Integration of sustainability in education
- EI criteria understanding and process
- EDI
  - Teamwork and inclusivity
  - Inclusivity in Criteria Development
  - Gender balance in engineering

Figure 3-5: Step Three. Examples of Nvivo coding example from Phase One (the interviews)

3.4.1.3.2 Phase Two (the EIAC)

Initial themes were constructed and highlighted within each feature of Engineering Education 5.0. This theme development (Figure 3-6) was grounded in a close reading of the document, focusing on how accreditation language and standards articulate expectations in, for instance, *lifelong learning*, *transdisciplinary education*, and *ethics*, which signal how the EIAC frames the future direction of engineering education in Ireland. These themes helped identify the implicit and explicit assumptions embedded within the criteria, particularly in relation to Engineering Education 5.0.

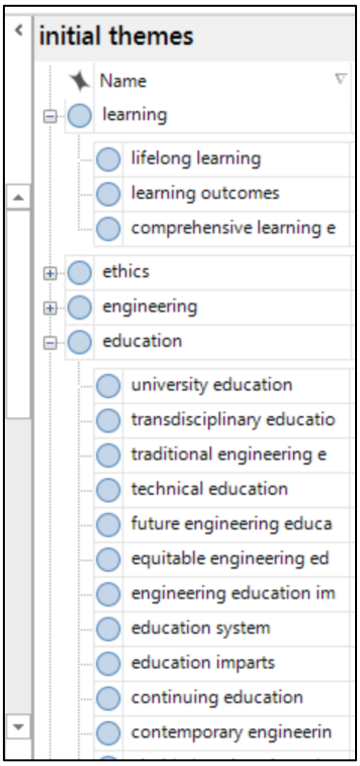
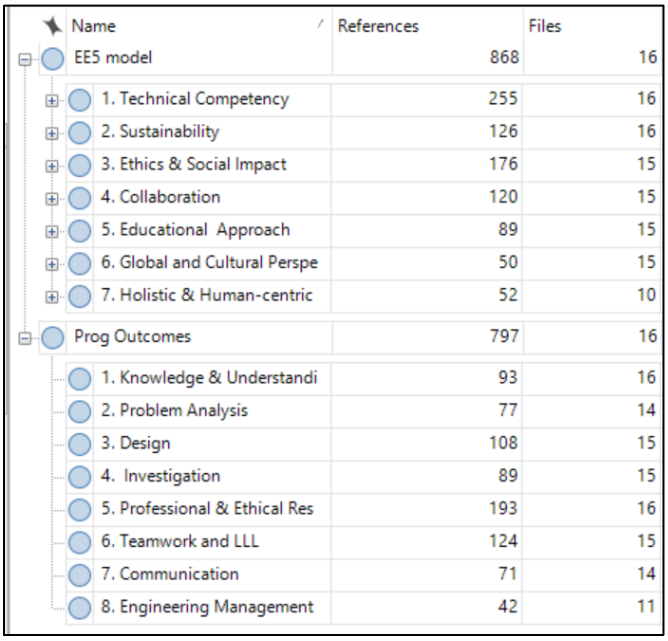


Figure 3-6: Step Three: Initial themes from Phase Two (the EIAC)

3.4.1.3.3 Phase Three: (the POs of the SARs)

Within the SARs, initial codes were reviewed and organised around the seven features of the Engineering Education 5.0 model. Themes were subsequently developed to reflect how the HEI interpreted and evidenced alignment with these features. Prominent themes included *Technical Competency*, *Ethics and Social Impact*, *Sustainability*, and *Collaboration*, highlighting areas of emphasis across institutions in demonstrating compliance with accreditation criteria. These themes were derived from repeated references to curriculum structures, teaching practices, stakeholder engagement, and graduate attributes linked to Engineering Education 5.0. Figure 3-7 also illustrates how the SARs presented the POs. These were analysed in parallel, allowing for a comparative view of how the HEI framed its alignment with the criteria. High-frequency themes such as *Professional and Ethical Responsibility*, *Teamwork and Lifelong Learning*, and *Design* indicate consistent areas of focus in the SAR narratives.



Name	References	Files
EE5 model	868	16
1. Technical Competency	255	16
2. Sustainability	126	16
3. Ethics & Social Impact	176	15
4. Collaboration	120	15
5. Educational Approach	89	15
6. Global and Cultural Perspe	50	15
7. Holistic & Human-centric	52	10
Prog Outcomes	797	16
1. Knowledge & Understandi	93	16
2. Problem Analysis	77	14
3. Design	108	15
4. Investigation	89	15
5. Professional & Ethical Res	193	16
6. Teamwork and LLL	124	15
7. Communication	71	14
8. Engineering Management	42	11

Figure 3-7: Step Three. Initial themes from Phase Three (the Self-Assessment Reports)

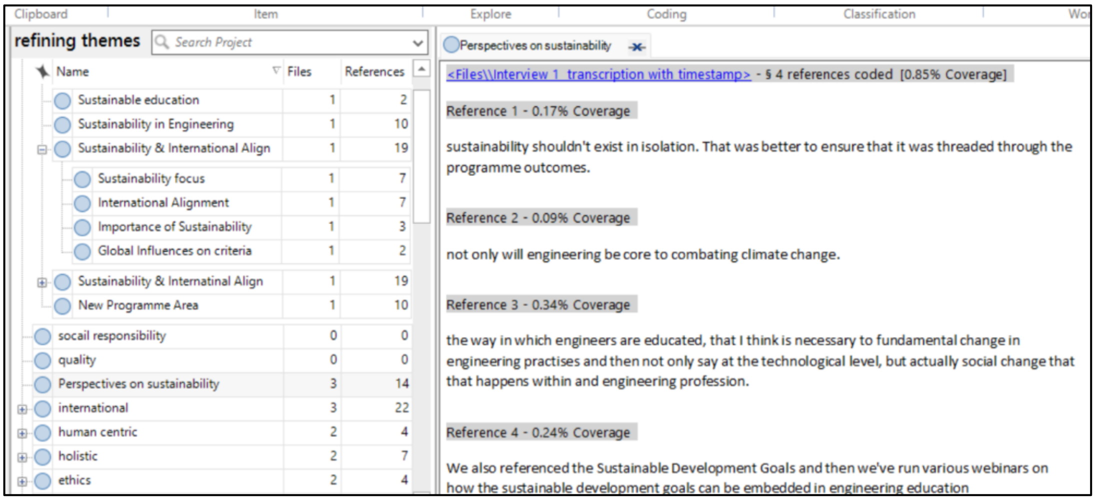
Differences across the POs in the SARs revealed nuanced interpretations of accreditation criteria, shaped by programme orientation or disciplinary focus. For example, while some programmes foregrounded *Sustainability* through project-based learning and community engagement, others integrated it more implicitly through engineering ethics modules.

3.4.1.4 Step four: developing and refining themes

In this step of RTA, initial themes were reviewed and refined to ensure they were coherent, conceptually distinct, and analytically meaningful (Braun and Clarke, 2006, 2019). Data extracts were re-examined for their relevance and alignment with thematic claims. Some themes were split, merged, or redefined, and subthemes were developed where necessary.

3.4.1.4.1 Phase One (the Interviews)

Themes generated from the interview transcripts were refined to ensure they accurately represented the underlying meaning of the coded extracts. During this phase, initial themes developed in Step Three were reviewed, compared, and condensed into more coherent and conceptually focused categories. This process of data reduction involved collapsing overlapping or similar codes and organising them into a final thematic framework for use in analysis and reporting. Figure 3-8 shows this refinement process by illustrating how multiple related codes, such as *Sustainable Education*, *Sustainability in Engineering*, and *International Alignment*, were grouped under a broader theme titled *Sustainability & International Alignment*. The left-hand panel shows the nested structure of refined themes, with sub-categories capturing nuanced dimensions of sustainability discussed by participants (e.g. *Sustainability Focus*, *Global Influences on Criteria*, and *Importance of Sustainability*). On the right, sample coded extracts from one interview transcript are presented under the sub-theme *Perspectives on Sustainability*. These excerpts illustrate how participants articulated the role of sustainability in shaping programme outcomes and the wider responsibilities of engineers. For instance, reflections on embedding the SDGs and the social dimensions of engineering education reveal how sustainability is conceptualised as both a technical and ethical imperative. This refinement stage ensured that the final themes were empirically grounded and conceptually robust.



Name	Files	References
Sustainable education	1	2
Sustainability in Engineering	1	10
Sustainability & International Align	1	19
Sustainability focus	1	7
International Alignment	1	7
Importance of Sustainability	1	3
Global Influences on criteria	1	2
Sustainability & Internatinal Align	1	19
New Programme Area	1	10
socail responsibility	0	0
quality	0	0
Perspectives on sustainability	3	14
international	3	22
human centric	2	4
holistic	2	7
ethics	2	4

<Files\\Interview 1 transcription with timestamp> - § 4 references coded [0.85% Coverage]

Reference 1 - 0.17% Coverage

sustainability shouldn't exist in isolation. That was better to ensure that it was threaded through the programme outcomes.

Reference 2 - 0.09% Coverage

not only will engineering be core to combating climate change.

Reference 3 - 0.34% Coverage

the way in which engineers are educated, that I think is necessary to fundamental change in engineering practises and then not only say at the technological level, but actually social change that that happens within and engineering profession.

Reference 4 - 0.24% Coverage

We also referenced the Sustainable Development Goals and then we've run various webinars on how the sustainable development goals can be embedded in engineering education

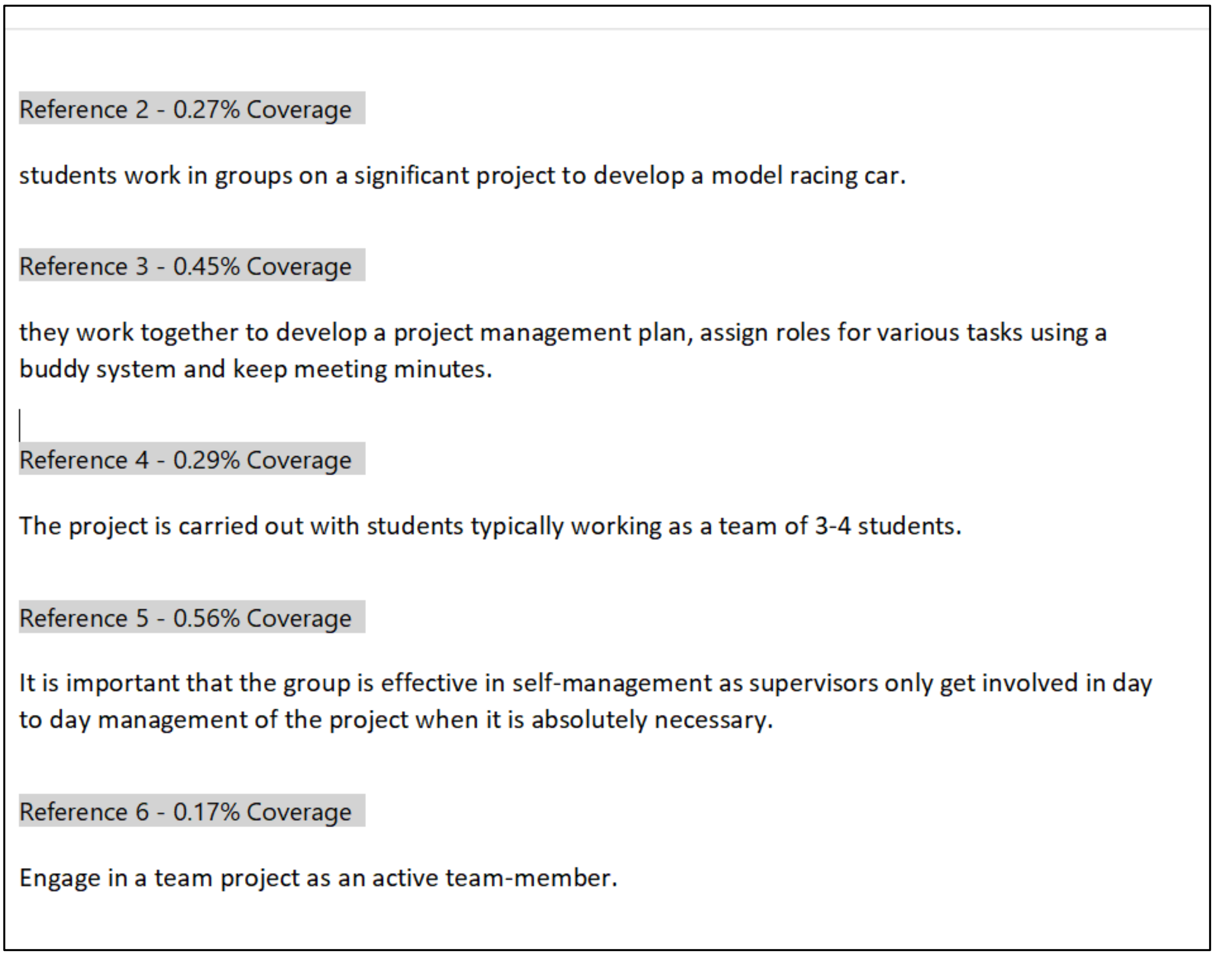
Figure 3-8: Step Four. Refining themes from Phase One (the interviews)

3.4.1.4.2 Phase Two (the EIAC)

Themes from the EIAC involved identifying the underlying assumptions and values embedded in the language in the EIAC, helping to distinguish between what was explicitly stated and what was implied. This involved close interpretive reading of how the criteria articulate expectations for engineering education, what is directly stated (such as required competencies or learning outcomes) and what is implied through emphasis or omissions. For example, recurring references to *lifelong learning*, *global awareness*, or *ethical responsibility* signal broader educational values being promoted as well as prescribe certain outcomes. Through this process, the emergent themes reflected how the EIAC shapes engineering education. For example, they included sustainability framed as a professional obligation, ethics and social responsibility as integral to technical practice, global awareness as core graduate attributes, and the prioritisation of lifelong learning and adaptability as central to professional identity.

3.4.1.4.3 Phase Three: (the POs of the SARs)

Themes from the SARs were further refined to capture how the HEI strategically represented its alignment with the Engineers Ireland accreditation criteria. This involved examining not only *what* was reported in relation to each PO but *how* it was conveyed, highlighting the strategies used to demonstrate compliance. The review process focused on identifying patterns in how the HEI constructed its narrative around programme design, teaching and assessment practices, graduate attributes, and engagement with external stakeholders. By refining the initial codes into more focused themes, the analysis clarified how the HEI interpreted and evidenced each PO, and how those interpretations varied across different programmes or departments. For instance, references to teamwork and lifelong learning may have been framed through group-based projects as illustrated in Figure 3-9.



Reference 2 - 0.27% Coverage

students work in groups on a significant project to develop a model racing car.

Reference 3 - 0.45% Coverage

they work together to develop a project management plan, assign roles for various tasks using a buddy system and keep meeting minutes.

Reference 4 - 0.29% Coverage

The project is carried out with students typically working as a team of 3-4 students.

Reference 5 - 0.56% Coverage

It is important that the group is effective in self-management as supervisors only get involved in day to day management of the project when it is absolutely necessary.

Reference 6 - 0.17% Coverage

Engage in a team project as an active team-member.

Figure 3-9: Step Four. Example of developing themes in Phase Three (the POS of the Self-Assessment Reports)

3.4.1.5 Step five: defining and naming themes

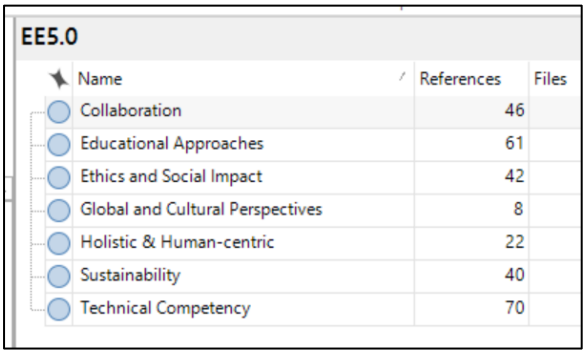
This phase involved refining and naming each theme to clearly reflect its central organising concept and analytic contribution (Braun and Clarke, 2020). Themes were evaluated for clarity, distinctiveness, and relevance to the research question and the framework of Engineering Education 5.0. Consistent with a social constructionist perspective, themes were developed to represent how participants made sense of their experiences and social realities. Rather than seeking objective truths, the focus was on how meaning was constructed through participants' narratives, shaped by their professional roles, cultural contexts, and interactions within the field of engineering education.

3.4.1.5.1 Phase One (the Interviews)

For the interview data specifically, themes captured how participants interpreted the seven features of the Engineering Education 5.0 model and articulated their views on the evolving role of engineering education. These included perceptions of ethics, sustainability, and the competencies needed for Industry 5.0. Each theme reflected participants' lived experiences and interpretive framings, while subthemes highlighted contextual nuances, areas of ambiguity, or tensions in meaning.

3.4.1.5.2 Phase Two (the EIAC)

Themes from the EIAC were defined by their relationship to the seven features of Engineering Education 5.0, reflecting the regulatory and conceptual assumptions embedded in the document. as shown in Figure 3-10.



EE5.0

Name	References	Files
Collaboration	46	
Educational Approaches	61	
Ethics and Social Impact	42	
Global and Cultural Perspectives	8	
Holistic & Human-centric	22	
Sustainability	40	
Technical Competency	70	

Figure 3-10: Step Five. Defining themes from Phase Two (the EIAC)

3.4.1.5.3 Phase Three: (the POs of the SARs)

Derived themes were organised around how the HEI positioned themselves within the accreditation framework and were crafted to reflect both strategic alignment and institutional voice, capturing how SARs balance narrative construction with evidential demands.

The final framework offered an integrated view of how intentions form accreditation board members, the EIAC texts, and accreditation processes intersect to shape engineering education in the context of Industry 5.0. The completion of this step provided a clearly articulated structure, ready for detailed reporting and discussion in the final phase, offering a coherent narrative grounded in the three data sources.

3.4.1.6 Step six: writing the final report

During this step, the researcher continued to refine the themes and labels for each theme. The writing of the report involved crafting an analytic narrative that integrated and interpreted the results across all three data sources (Braun and Clarke, 2006, 2019) as outlined in Chapter Four. The narrative then moved beyond description to offer insights and critical interpretation, as shown in Chapter Five.

3.4.2 Trustworthiness of the research

This study was grounded in a social constructionist perspective, which recognises that knowledge is not discovered as an objective truth but co-constructed through interaction, discourse, and interpretation (Cohen *et al.*, (2017). Trustworthiness in this context is about making transparent the interpretive practices that shaped the analysis and demonstrating how the findings are situated, credible, and coherent within their context. It is not about eliminating researcher influence. To ensure rigour, strategies consistent with Lincoln and Guba's (1985) four criteria, credibility, transferability, dependability, and confirmability, were applied in ways that align with the study's philosophical stance and design.

3.4.2.1 Credibility

Credibility was supported through triangulation of three data sources: semi-structured interviews with Engineers Ireland accreditation board members, the 2021 EIAC, and the POs of programme self-assessment reports (SARs). Each dataset was analysed using Braun and Clarke's reflexive thematic analysis, with multiple readings, coding cycles, and theme refinement. Reflexive memos captured tensions in interpretation, such as when sustainability was framed as both central and tokenistic across different accounts.

Given the researcher's professional background in engineering education and accreditation, the potential for bias was recognised from the outset. To avoid imposing predetermined views on the data, several strategies were adopted. First, NVivo was used to systematically code and store all data extracts, ensuring that interpretations were grounded in evidence rather than assumptions. Second, coding decisions and theme development were documented through memos, making shifts in interpretation transparent. Finally, triangulation across interviews, accreditation criteria, and SARs reduced the risk of privileging any one perspective. Together, these practices supported credibility by acknowledging the researcher's positionality while demonstrating that findings emerged through careful, reflexive engagement with the data.

3.4.2.2 Transferability

From a social constructionist perspective, transferability does not involve universalising the findings but offering sufficiently detailed accounts of context so that readers can consider resonance with other settings. This study provides thick description of the perspectives of accreditation board members on Engineers Ireland's updated accreditation criteria, and the institutional responses captured in the POs of the SARs. These detailed contextual accounts allow others, scholars of engineering education, policy actors, and accreditation practitioners, to assess whether and how the insights may be meaningful in their own environments.

3.4.2.3 Dependability

Dependability was addressed by maintaining a transparent and traceable account of the analytic process.

A chain of evidence was established and maintained throughout the research process as a way to minimise the errors and biases in the research. This chapter essentially serves as a record of the systematic approach adopted, enabling a reader or auditor to check the research stage by stage and certify that the conclusions are justified (Yin, 2018).

NVivo served as an audit trail, recording coding decisions, the evolution of categories, and the refinement of themes across the three datasets. Rather than aiming for replication, dependability in this study means that the interpretive pathway can be followed and understood by others. Reflexive memos and analytic notes ensured that shifts in focus were captured and explicitly justified within the analysis. For example, heightened attention to human-centric responsibility as Industry 5.0 values became salient during the coding process. These memos were not utilised as a data source; instead, they functioned as part of the audit trail, outlining the steps taken by the researcher and maximising the rigour of the approach.

3.4.2.4 Confirmability

Confirmability was approached by foregrounding reflexivity and triangulation. Reflexive memos documented how the researcher's professional background and theoretical orientation influenced interpretation, acknowledging this influence as part of the knowledge-making process. A researcher's positionality statement and account of her worldview were outlined in Section 1.5 which recognises researcher bias, which could influence and inform methodologies and findings (Creswell and Creswell, 2018).

The use of three distinct but related data sources (interviews, EIAC, SARs) created opportunities to identify convergences and divergences in the construction of accreditation and Industry 5.0, which strengthened the analysis by situating findings across multiple perspectives. NVivo further supported confirmability by making analytical decisions transparent.

Together, these strategies demonstrate trustworthiness by showing that the findings are credible, contextually situated, and reflexively grounded. Rather than aspiring to produce detached or generalisable truths, the study's rigour lies in its careful documentation of how meaning was constructed in and through the accreditation context of Irish engineering education, and how the researcher engaged reflexively with this process.

3.5 Ethical considerations

This research study was conducted in accordance with the ethical guidelines of Dublin City University and research ethics approval was granted by the Research Ethics Committee based on a comprehensive research ethics submission in Spring 2023. Approval from the DCU ethics committee was confirmed in the letter shown in Appendix E. The NDA between DCU and Engineers Ireland facilitated access to data which complied with all ethical standards.

To inform and encourage participation in the interviews, the target group was provided with both a written and oral overview of the study. This included the research aims and purpose, the reasons for individual participation, the methods of data collection, and details on how and to whom the findings would be reported. An Informed Consent Form (ICF) (Appendix C) and a Plain Language Statement (PLS) (Appendix D) were given to each participant, and they were given an opportunity to ask clarifying questions and make a fully informed decision regarding their participation. The researcher’s contact email was included in the invite along with a brief overview of the topic of interest. It was made clear to participants that their involvement was voluntary, they could withdraw at any stage, and their identities would be anonymised. For the SARs, it was recognised that they may contain sensitive institutional information. Ethical protocols were rigorously followed to ensure the anonymity of the HEI and the confidential handling of all documents throughout the research process.

This chapter has outlined and justified the methodological approach and the research design for this study. The results from the study are now presented in Chapter Four.

Chapter: 4 Results

4.1 Introduction

Guided by the overarching research question, this chapter presents the results of the study.

> **Through the lens of Engineering Education 5.0, how does accreditation in engineering programmes at a Higher Education Institution in Ireland prepare students for Industry 5.0?**

Data was collected from three data sources: (i) interviews with Engineers Ireland accreditation board members, (ii) the 2021 Engineers Ireland Accreditation Criteria (EIAC), and (iii) institutional self-assessment reports (SARs). Each of these data sources was treated as discursive artefacts through which meanings around Engineering Education 5.0 are co-produced, negotiated, and enacted within the accreditation process. Using reflexive thematic analysis informed by a social constructionist perspective, the analysis focused on how discourses within and across these sources framed particular understandings of Industry 5.0 using the Engineering Education 5.0 model devised in Chapter Two.

This chapter presents the results of the study, structured around the three sub-research questions and which in turn correspond to one of Ball's (1993) three contexts: policy text production, and practice. The structure for presenting the results is outlined in Table 4-1.

Table 4-1 Structure for presenting the results

Section	Sub research question	Data Source	Policy Context (Ball, 1993)
4.2	Through the lens of Engineering Education 5.0, how do members of the accreditation board of Engineers Ireland understand the current accreditation criteria?	Interviews	Policy as Discourse (Context of Influence)
4.3	How does the 2021 EIAC represent Engineering Education 5.0?	EIAC Document	Policy as Text (Context of Text Production)
4.4	How is Engineering Education 5.0 represented in the POs of SARs?	Self Assessment Reports	Policy as Practice (Context of Practice)

Each section provides thematically organised analyses around the seven features of Engineering Education 5.0, illustrated with excerpts from interviews, EIAC texts, and the POs from the SARs that together present multiple perspectives and show how meanings are constructed across different sources.

4.2 Accreditation board's understanding of Engineering Education 5.0

To address sub-research question one (How do members of the accreditation board of Engineers Ireland understand current accreditation criteria through the lens of Engineering Education 5.0?), this section explores how board members construct and negotiate the role of professional accreditation in shaping engineering education for Industry 5.0. The synthesis in Table 4-2, foregrounds how meaning is co-produced through language and professional narratives, exposing areas of support, tension, ambiguity, and competing priorities.

Table 4-2: Summary of Phase One interpretations

Feature of Engineering Education 5.0	Key Interpretations & Tensions
Technical Competency	Strong emphasis on data and AI; concerns about curriculum space and speed of change
Sustainability	Seen as essential but interpreted variably (technical vs. systemic change)
Ethics & Social Impact	Broad consensus on importance; debate on how to embed it
Collaboration	Viewed as essential; international accords are key drivers
Educational Approach	Lifelong learning emphasised; personalisation and flexibility underexplored
Global & Cultural Perspectives	Agreement on mobility; varied engagement with different cultures
Human-Centricity	Support for inclusion; differing views on formal EDI initiatives

As outlined in Chapter Three, interviews were conducted with three members of the accreditation board of Engineers Ireland, each of whom had extensive experience in engineering education and specific insight into the development of accreditation criteria. As board members, they brought situated perspectives to the research, which were shaped by role, history, and practice.

This Context of Influence (Ball, 1993) explores the intentions of the accreditation board when developing the 2021 updates of the EIAC which include: a new PO focused on Engineering Management (PO8), an emphasis on the management of knowledge and the application of management principles relevant to engineering disciplines; the introduction of dedicated PA for sustainability, aligning engineering education with sustainable development goals; an increased emphasis on data science, analytics, and ethical usage of technology and data (Engineers Ireland, 2021).

Analysis found that the interviewees perceived that all seven features of Engineering Education 5.0 are present in the EAIC. However, they had different understandings of these features as well as different beliefs in terms of how they should be articulated within the accreditation criteria.

4.2.1 Technical competency/ emerging technologies in engineering education

Emerging technologies refer to innovations in the early stages of development or adoption that have the potential to impact various fields of engineering significantly (Zeb *et al.*, 2022). Before presenting the evidence, two points should be noted. First, the traditional focus on technical competencies, particularly in POs 1-4, has been well-established in previous versions of accreditation criteria and was not a central topic of the interviews. Second, the interviews centred on the development and purpose of the latest EIAC criteria published in 2021, which were developed before the emergence of disruptive generative AI technologies in 2022. Thus, interviewees' views on AI, discussed after the release of tools like ChatGPT, inevitably reflected the growing influence of these technologies in engineering education. The sub-themes in this feature revolve around interviewees' views on addressing emerging technologies in engineering education and what they view as the challenges in integrating emerging technologies into accreditation criteria.

4.2.1.1 Addressing emerging technologies in engineering education

The growing importance of emerging technologies in the engineering profession and the need to address them as part of engineering education were identified by all three interviewees. I#1 shared the results of a survey conducted during the accreditation criteria review process, which revealed that "the top trends would have been, digitalisation, including new digital tools". I#1 felt that "students should have an understanding of the fundamentals and exposure to different technologies so that they can adapt to new technologies as they arise and as they inevitably will".

The integration of AI, especially generative AI, was recognised by all three interviewees as becoming increasingly significant within engineering education, who highlighted its relevance to both academic and industry settings. Noting that it is not yet explicitly stated in accreditation criteria, they emphasised the need for graduates to be prepared for AI-centric work. According to I#3, AI is "embedded in practice", essential for "training future engineers". I#3 also reflects on the obligations of engineering education regarding AI; "We have to look at actually training or educating our students to be able to go into an industry where they're going to need probably to be using AI". This viewpoint is echoed by I#1, who noted that "students are already using it. Once they get into the workplace, this will be even more prevalent".

Second, interviewees viewed automation and robotics as increasingly influential in engineering, with I#1 identifying them as critical in shaping the field. However, I#2 favours a human-centered approach to automation, particularly in the developing field of collaborative robotics. They suggest that, while machines excel at certain tasks, human intervention is essential to "add smarts.". I#2 questions how long this human role will remain critical, especially with the convergence of generative AI, robotics, and cybernetics. As I#2 notes, “if you take robots and you add artificial intelligence… then you’re in a different space, where the necessity for human involvement may continue to decrease”, indicating a belief that as automation advances, employees and educational bodies must prepare for evolving roles.

Third, data analytics was recognised by all interviewees as a key element of future engineering practice, albeit with differing views. I#3 noted that, although data analytics is not explicitly referenced in the POs, from their experience, it is nonetheless deeply embedded in departmental teaching and practice. I#1 highlighted the importance of preparing engineers to work with “advanced digital tools and data-driven technologies.” However, I#2 had an alternative approach and viewed data analytics as a modern repackaging of traditional statistical methods. If some view data analytics as new and transformative while others see it as traditional, this could result in inconsistent integration across departments or a potential misalignment with industry expectations.

4.2.1.2 Challenges integrating emerging technologies into accreditation criteria

Interviewees discussed how the Engineers Ireland accreditation board should address emerging technologies. I#1 acknowledged that the result of growing awareness of AI’s impact on engineering students, may soon be formally “called out” in accreditation criteria and that collaboration with academic partners could guide how it is embedded in existing programmes. When it comes to the detail of integrating emerging technologies into accreditation criteria, some caution remains. I#2 expressed concern about AI, suggesting it should be treated as “a subset of some criterion, like ethics” rather than a standalone accreditation criterion.

Given the rapid pace of change, interviewees also identified a range of challenges in the integration of emerging technologies into engineering accreditation. These include relevance, curriculum constraints, assessment and ethical considerations. First, the difficulty of keeping accreditation relevant when "reviews may only happen every five years," was highlighted with I#1 stressing the need to keep academic programmes aligned with evolving industry standards, particularly in "digitalisation, including new digital tools." Furthermore, I#1 raised concerns about academic integrity, asking if assessments need to be redesigned, possibly favouring "more interviews or hands-on work, rather than writing essay-style questions" to mitigate AI’s impact.

Second, curriculum constraints present a challenge, as I#2 notes "There's only a finite amount of space in a curriculum to establish all these POs", arguing against early specialisation, which risks "pigeonholing people into small boxes too early." They also highlight the problem of obsolescence, warning that emerging technologies may become outdated before they are fully integrated: "We don't know what artificial intelligence is going to look like in 12 months' time, never mind five years."

Third, the difficulty of assessing learning outcomes in an era where AI tools are readily available was highlighted by I#3, “there will be challenges around accreditation evidence… how do we assess what they’ve learned when tools like generative AI are so widely available?”

Finally, ethical considerations relating to emerging technologies, particularly AI, were of concern to all interviewees. I#1 advocates for the inclusion of AI within engineering curricula, emphasising that this "must be done with careful attention to the ethical implications of its use." They highlight the broader ethical responsibilities of engineers, stating, “You're not just designing technology for ruthless efficiency or cost... you're considering the human and environmental impact of your engineering work.” Given this, the need to ensure that graduates are well-prepared for responsible technology use in professional settings was stressed. I#3 underscores the need to educate students on the ethical use of AI, arguing,

> *We have to look at actually training or educating our students to be able to go into an industry where they’re going to need... to be using this and how do they do that ethically.*

When it comes to accreditation, I#2 questions where ethical concerns linked to emerging technologies could fit within the existing POs. Additionally, I#3 links ethical considerations to data-driven technologies, including computer vision, which often have human elements and necessitate an ethical approach. Reflecting on the development of ethical criteria, they assert, “even though it’s not called out, it’s very much on our agenda as part of the overall ethics piece”, highlighting the priority given to ethical awareness of technology in accreditation.

4.2.2 Sustainability

Overall, the perceptions of the interviewees relating to sustainability emerged as complex and multi-faceted, ranging from a focus on environmental concerns to a broader, more holistic integration across various aspects of the discipline. From an engineering education perspective, the three interviewees share a belief that sustainability is more than a technical solution; rather, it is an integral part of a broader approach to providing graduates with the ability to view sustainability as an all-encompassing feature. The interviewees did not have a shared understanding or perspective on sustainability, nor did they agree on how sustainability should be included in accreditation criteria.

4.2.2.1 Different perspectives on sustainability

The integration of sustainability within engineering education brings diverse perspectives from the interviewees. While each emphasised the importance of sustainability, they equally highlighted practical challenges. I#1 strongly advocates for sustainability to be deeply embedded throughout POs rather than treated as a separate topic, arguing that it should drive both “technological” and “social change” in engineering practices. For them, sustainability shapes how engineers approach problem-solving, linking closely with critical thinking and ethics to address pressing issues like climate change, stating, “sustainability shouldn’t exist in isolation…Not only will engineering be core to combating climate change... it is necessary to fundamentally change engineering practices.” I#2, however, sees sustainability as a broad, often ambiguous term that risks becoming a buzzword. They describe it as “a nebulous concept” and suggest it should be viewed as an ongoing practice rather than a fixed outcome, noting the difficulty in capturing it as a PO. I#2 also conceptualises sustainability beyond environmental concerns, advocating for an inclusive view that considers economic and social dimensions. They argue for a focus on sustaining the engineering profession itself, pointing out that “what engineers do now is very different from what they did 20-30 years ago”. I#3, on the other hand, observes that sustainability has already become normalised within engineering, suggesting that the profession may be “ahead of the curve.” They highlight the influence of global partnerships and international standards in embedding sustainability, anticipating that it will soon become a mandated part of engineering curricula through cooperative frameworks. Despite the challenges of full integration, I#3 sees sustainability becoming an interdisciplinary focus, stating it will affect “everything we do” in engineering education.

Collectively, and despite their differing opinions, the views of the interviewees underscore a shared commitment to sustainability’s role in addressing global challenges. Although holding differing perspectives, interviewees agree that sustainability is an essential part of engineering education, and it requires a “fundamental change in engineering practices” to truly meet the demands of sustainable development” (I#1).

4.2.2.2 Intention of Engineers Ireland response to sustainability in accreditation criteria

Insights from all interviewees suggest that Engineers Ireland’s approach to sustainability in accreditation is evolving towards a more embedded and pervasive model, recognising it as a core principle that aligns with industry trends and stakeholder expectations. As stated by I#1, “the main trend that came through the stakeholder engagement was the importance of sustainability.” With I#3 asserting that it is “normal in our culture” and will soon be “front and centre” in future iterations of accreditation. However, although interviewees agreed on its importance, they differed on whether sustainability should be classified as a PO or a broader crosscutting PA.

Both I#1 and I#2 viewed sustainability as an ongoing practice that should be embedded across the criteria, not an outcome. According to I#2, sustainability is “a pervasive practice across everything you're doing within your programme.” with I#1 noting, “the best and most natural way to deal with that was to have it embedded across multiple modules”, while I#3 states, sustainability “is not captured by the stratification of the POs…But it is there in the education.” This universal approach aligns with Engineering Education 5.0, where sustainability is advocated to be woven throughout the curriculum.

Finally, it was observed that some forward-thinking programmes have been embedding sustainability for years, as reflected in recent self-assessment reports, which show “increasing evidence” (I#1) of sustainability practices, even under the older criteria. This proactive integration highlights the ongoing shift towards sustainability as a central, continuous theme in professional engineering accreditation criteria rather than a standalone objective.

4.2.3 Ethics and social impact

In 2014 EAIC, Ethics and Professional Responsibilities was enhanced as a standalone PO All interviewees agree that its inclusion was a positive development, reflecting a broader and more integrated approach to professional and ethical responsibilities and social impact. Interviewees outlined their views on further expansion of ethical considerations and how they should be addressed in the updated 2021 accreditation criteria.

4.2.3.1 Views on ethics and social impact

The views of the interviewees highlight a shared commitment to integrating ethical awareness and social impact into engineering education. They agree that ethics should influence both technical and societal aspects of engineering, preparing future engineers to make socially conscious decisions that extend beyond scientific application to broader societal benefit. To this end, interviewees emphasise the importance of integrating ethics and social impact throughout engineering education, viewing it as essential for socially responsible practice. For example, I#1 advocates for embedding ethical thinking across various POs, linking it to “design, sustainability, and engineering practice” and asserting that engineers should consider the “human and environmental impact” of their work, seeing ethical awareness as central to problem-solving and decision-making.

Collectively, the interviewees advocate for a universal approach that distinguishes engineering from science, highlighting the profession’s broader responsibility to society. These insights underpin a common approach to preparing engineers who are both technically competent and socially aware, capable of making decisions that benefit society beyond mere scientific application.

I#1 describes engineers as agents of social change and calls for a “fundamental change in engineering practices” that includes a shift not only in technology but also in the profession’s social role. I#2 echoes this sentiment, stressing that “the most technically correct solution might not be the most appropriate solution in a social context.” While I#3 acknowledges that ethics and societal impact are already present in the accreditation framework, they call for greater emphasis on “compliance, health, and safety” as part of a comprehensive ethical approach. These insights underpin a common approach to preparing engineers who are both technically competent and socially aware, capable of making decisions that benefit society beyond mere scientific application.

4.2.3.2 Enhancements and updates to ethics in accreditation criteria

Ethics is increasingly viewed by the interviewees as a pervasive element rather than a standalone requirement. Regarding the development of the 2021 accreditation criteria, they shared views on the increased emphasis on human-centred design and user-centred considerations in the document, as well as on the incorporation of end-user concerns in POs, embedding ethics across the curriculum and the challenges of systematic ethics integration.

All three interviewees highlight a growing focus on the ethical responsibility of engineers to consider the needs and values of those impacted by their work. For example, I#1 discusses the importance of human-centred design, noting how the accreditation review brought attention to areas like "accessibility of buildings" and "user-centred design" for products, indicating a shift towards considering diverse end-users in both physical and digital design. They explain that the updated PO5 now includes “responsibilities of people” in design, encouraging engineers to prioritise human and environmental impact over purely technical objectives.

Embedding ethics across the curriculum continues to be an important topic. I#1 and I#2 highlight a shift from isolated modules to a more integrated approach, where ethics is woven throughout the curriculum. I#1 notes the move towards “professional responsibilities towards people and the environment,” moving beyond technical skill to include ethical and social awareness. I#2 agrees, stating that while ethics is a PO, “it was embedded... these things are important, but they're not unique outcomes.” This holistic approach is seen as more effective for ethical education than standalone modules.

Challenges of systematically embedding ethics were also noted by I#2, who opined that some institutions initially adopted standalone ethics modules but found integration across multiple modules more effective. The inclusion of the new PO8 (Engineering Management) was also seen as a solution to these difficulties, especially as it is driven by industry needs for “compliance, health and safety,”(I#3) alongside ethics. I#3 also observes that the industry stakeholders were “more vocal” about these areas, signalling their critical role in modern engineering practice.

4.2.4 Collaboration

Like ethics, collaboration is now well-established in Engineers Ireland accreditation criteria via the teamwork element of PO6 (Teamwork and Communication). Interviewees consistently emphasised the importance of teamwork, particularly in broadening the skills and attitudes that graduates are expected to develop for effective collaboration. They recounted how discussions on the updates for the 2021 criteria focused on teamwork as a core competency, collaboration within international accords and integration of teamwork in engineering education. Here, the results reveal how collaboration is understood by the interviewees in both engineering education and accreditation, highlighting its role in developing well-rounded graduates, aligning with international standards, and preparing students for multidisciplinary, real-world professional environments.

I#2 opined that teamwork is developed through practical group work and capstone projects, where students learn “to deliver projects on time, on specification, within budget,” gaining experience in project and resource management from the early stages of their education. I#1 viewed collaboration as essential for producing “rounded graduates” with key professional skills. They also highlight teamwork as a core component of non-technical skills central to the accreditation process.

The accreditation criteria are also influenced by international frameworks, with I#2 and I#3 noting the importance of agreements like the Washington, Sydney, and Dublin Accords as “primary drivers” for quality standards. I#3 further explains that collaboration within the accreditation process itself is “collegial…for the benefit of the profession and maintaining quality,” involving peer comparisons with international bodies and partnerships with Irish industry and educational institutions.

Teamwork is also connected to the realities of the modern workforce, where engineers work across disciplines and cultures. I#3 stresses that “nobody works really in a silo anymore,” highlighting employers’ demand for engineers who are not only collaborative but also inclusive and adaptable in diverse, multidisciplinary settings.

4.2.5 Educational approaches

Engineering Education 5.0 promotes continuous and personalised learning as core educational values. While the version of the accreditation criteria prior to 2021 included a PO focused on lifelong learning, the results from this study indicate that the updated criteria continue to emphasise the importance of continuous professional development (CPD) and self-directed learning. Interviewees consistently reinforced the value of lifelong learning, highlighting its relevance in the context of rapidly evolving technological landscapes.

Although interviewees discussed the growth of online learning in the post-COVID-19 environment, there was no specific mention of personalised learning in relation to the development of accreditation criteria. This omission is unsurprising, as Engineers Ireland’s remit does not extend to prescribing pedagogical approaches or modes of delivery.

The commitment to continuous learning is reflected in PO6, which identifies teamwork and lifelong learning as essential graduate attributes. However, some interviewees believe this aspect could be more strongly emphasised. As I#3 noted, “It’s probably not as highlighted as it should be,” suggesting a need to better foreground adaptability within engineering education. I#2 further linked adaptability to programme sustainability, stating that “programmes have to deliver the foundation... that allows graduates to be upskilled and to evolve as the profession evolves.”

The shift to online learning during the COVID-19 pandemic was also seen as a catalyst for educational innovation. I#1 observed that the pandemic revealed “major benefits to online learning for part-time learners,” while also stressing the importance of maintaining hands-on experiences critical to developing practical engineering skills.

Although not explicitly addressed in accreditation criteria, the emergence of accredited apprenticeships was highlighted by I#1 as an example of flexible educational pathways. They noted, “We now have three accredited... professional engineering apprenticeships,” which blend academic instruction with practical, work-based learning.

Overall, interviewees underscored the importance of a robust foundation in lifelong learning to support the evolving demands of the engineering profession. The results suggest a need for greater emphasis and clearer articulation of how continuous learning can be integrated and supported within accredited programmes.

4.2.6 Global and cultural perspectives

Global and cultural perspectives reflect the need for a world view in engineering to ensure that engineering solutions are centred around future needs. While the interviewees consistently highlighted the importance of graduate mobility enabled by aligning educational standards across countries with international accords, there was less consensus on the need to recognise and integrate cultural diversity within engineering practice. I#2 explains that the Washington, Sydney, and Dublin Accords require “commonality across the criteria for evaluation” to ensure mutual accreditation globally. I#3 further links this alignment to the quality of Irish graduates, noting that adherence to international standards enhances the reputation of Irish engineering qualifications. As a result, these engineering qualifications are recognised worldwide, enabling graduates to pursue international career opportunities. I#1 emphasises that “the international component is extremely important” as it allows for “international mobility for graduates as well as welcoming in other international engineers,” which contributes significantly to the Irish economy.

Interviewees also acknowledge the growing significance of cultural awareness within the profession. I#3 emphasises inclusivity as a valued skill, noting that “working with a diverse group” is increasingly expected by employers. They point out that diversity in classrooms and workplaces is now the norm, reinforcing the need for culturally aware training in engineering education. I#1 links cultural awareness to international frameworks, which support “cultural exchange and professional mobility,” helping graduates adapt to different cultures. However, I#2 asserts that engineers “really care if you can do the job” over cultural differences.

Overall, these points illustrate a commitment to preparing engineers for a global profession, with international agreements supporting mobility and qualifications while fostering a culturally aware and inclusive approach.

4.2.7 Holistic and human-centricity

Human centricity is one of the pillars of Industry 5.0 and Engineering Education 5.0 encapsulates the idea of a comprehensive education that integrates technical skills with an understanding of their applications in a real-world human-focused context. The results show that interviewees view a human-centred approach as a core aspect of engineering education, alongside the ability to combine technical skills with a broader understanding of their real-world applications.

4.2.7.1 Human-centred and holistic approach

There was evidence from the interviewees concerning gender balance and equality, diversity and inclusion (EDI). I#1 emphasises the importance of diversity on Engineers Ireland's accreditation board, particularly efforts toward gender balance, although acknowledging that "we're not quite there yet". They also highlight the inclusion of the National Disability Authority in accreditation visits to ensure that engineering solutions reflect universal design principles, addressing accessibility and inclusivity in line with the principles of EDI.

In a more critical view of formal EDI initiatives, I#2 expresses scepticism towards structured diversity initiatives, viewing the engineering profession as inherently inclusive and merit-based. They argue that there has "never been an impediment for women to get into engineering," suggesting that some diversity challenges may be overstated. They emphasise that capability, rather than background or identity, should be the focus, seeing formal initiatives like Athena Swan[14] as potentially unnecessary or even counterproductive.

In contrast, I#3 stresses that inclusivity is increasingly valued in the workforce, noting that employers seek engineers who can "work with a diverse group" in multidisciplinary teams. They also highlight gender imbalances across disciplines, observing that biomedical engineering recently had a "60% female" cohort while other fields remain male-dominated.

Overall, interviewees underscore the need for a human-centred approach that values inclusivity and accessibility, though views diverge on the role of formal EDI initiatives. While I#1 and I#3 acknowledge inclusivity as essential for effective engineering practice, I#2 suggests that diversity should focus on capability rather than structured initiatives. This approach aligns with a broader vision of engineering that is both people-focused and adaptable to diverse social contexts.

4.2.7.2 Integration of technical skills and their application in accreditation criteria

The integration of technical skills with broader real-world applications is seen as necessary by all interviewees. I#1 underscores the need for "rounded graduates" who combine technical expertise with non-technical skills, highlighting that Engineers Ireland's POs are designed to balance "technical expertise in maths and science and technology" with "ethical awareness, communication skills, teamwork skills, and management."

I#2 adds that engineering education must prepare graduates for management roles, as "ten years after graduation, most of them are in some sort of management role." They stress the

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[14] https://www.advance-he.ac.uk/equality-charters/international-charters/athena-swan-ireland

importance of project and people management skills, noting that an engineer's responsibilities often extend beyond technical tasks to encompass broader organisational and societal roles.

I#3 emphasises that students must be able to apply their technical skills within real-world contexts, pointing to the collaborative development of PO8 with employers. They explain that "employers were saying more, 'what do we need the graduates to have?'" which led to a PO focus on teamwork, complex problem-solving, and industry relevance.

4.2.8 How do accreditation board members interpret accreditation's role in Engineering Education 5.0?

The results from Phase One suggest that interviewees' views of the intent behind the 2021 updates to the EIAC indicate a shift toward the principles of Engineering Education 5.0, promoting a more holistic, adaptive, and socially responsible approach to engineering education. Interviewees identified the inclusion of features such as ethics, sustainability, collaboration, and human-centred design as aligning with evolving professional and societal demands. Ethics and technical competencies were viewed as particularly well-integrated into accreditation criteria, reflecting their alignment with industry needs and established evaluation mechanisms. However, features such as sustainability and holistic approaches showed more variability in both interpretation and implementation. While interviewees acknowledged the relevance of global perspectives, collaboration, and educational innovation, these were less prominently discussed and appeared to be less consistently linked to concrete developments or broad consensus. The updated EIAC was recognised for its responsiveness and flexibility, though interviewees also expressed a desire for stronger emphasis on emerging areas such as AI and intercultural competence. Overall, board members construct accreditation as both a quality assurance process and a forward-looking tool for shaping the future of engineering education in line with Industry 5.0's human-centric and socially responsible agenda. These results are discussed in greater detail in Chapter Five.

4.3 Engineers Ireland accreditation criteria and Engineering Education 5.0

This section presents the results of the document analysis of the 2021 EIAC (Engineers Ireland, 2021) to address sub-research two: How does the 2021 EIAC represent Engineering Education 5.0? A high-level summary of the results is shown in Table 4-3.

Table 4-3 High level summary of the Phase Two interpretations

Feature of Engineering Education 5.0	Key Interpretations & Tensions
Technical Competency	Strong (data, digital tools); AI not explicitly addressed
Sustainability	Strong in PA7; fragmented elsewhere
Ethics & Social Impact	Strong in PO5; links to design and sustainability
Collaboration	Present in POs 6–8; lacks emphasis on interdisciplinary problem-solving
Educational Approach	Emphasised in CPD; less on personalisation or inclusion
Global & Cultural Perspectives	Referenced in mobility; less explicit in POs
Human-Centricity	Support via UD and EDI; weak on accessibility and diverse learners

As explained in Chapter Three, this process entailed in-depth analysis of the mandatory Programme Outcomes (POs) and cross-cutting Programme Areas (PAs). Indicators of all seven features are discernible in the EAIC, albeit to varying degrees. This section first considers the Foreword and Introduction text before revealing the results from the POs and PAs.

The Introduction and Foreword sections set the tone for the EIAC. The Foreword functions as an authoritative context-setting and justification for the accreditation criteria, reaffirming Engineers Ireland's legal and historical position and communicating the purpose and value of accreditation while highlighting the updates in the 2021 criteria. The Introduction is more practical and user-focused, explains the scope of the document, describes the pathways to professional titles, and underscores the international relevance and recognition of Engineers Ireland's memberships in global accreditation bodies. Analysis reveals that each of the seven features is addressed. As illustrated in Table 4-4, key features are highlighted, such as technical competency and sustainability, aiming to prepare graduates to keep pace with technological change while also addressing ecological and societal challenges. Ethical practice, social impact, and human-centred approaches are emphasised to support the development of socially responsible engineers. Collaboration, along with global and cultural perspectives, is recognised as essential for interdisciplinary teamwork and international mobility, while inclusivity and adaptability are promoted.

Table 4-4: Engineering Education 5.0 in Foreword and Introduction of EIAC

Feature	Evidence from EIAC	Observations
Technical Competency	The updates include "coverage of data science, analytics, and the ethical usage of technology and data" (p.1), addressing technological advancements in the curriculum.	Aligns with Engineering Education 5.0's emphasis on technological progress, though implementation details are not specified.
Sustainability	PA7 (Sustainability) integrates ecological and societal aspects, aiming to "meet international standards and support social, environmental, and economic goals" (p.1).	Strong alignment with balancing technology and sustainability, but lacks specifics on incorporating these principles into the criteria.
Ethics and Social Impact	Emphasises "high ethical standards," "professional and social responsibility," and "equality, diversity, and inclusion in professional practice" (pp. 1, 3).	Reflects Engineering Education 5.0 principles
Collaboration	Highlights interdisciplinary teamwork, stakeholder involvement (e.g., industry professionals and academics), and international collaboration agreements (p.3).	Encourages collaboration to solve complex challenges, aligned with Engineering Education 5.0's collaborative ethos.
Educational Approaches	Includes principles of "inclusion" (p.1), flexibility, and adaptability to societal changes, supporting continuous learning.	Aligns with Engineering Education 5.0 but lacks details on personalising education to fully address diverse learning needs.
Global and Cultural Perspectives	Focuses on international mobility and global standards, with membership in agreements like the Washington Accord and ENAEE.	Supports international mobility but prioritises accreditation over fostering cultural awareness or deeper global context integration.
Holistic and Human-Centric	Stresses "professional and social responsibility" (p.3) and "equality, diversity, and inclusion" (p.1), integrating technical skills with an understanding of the human context.	Strong alignment with Engineering Education 5.0's holistic focus, though practical implementation details remain underexplored.

The next sections present an overview of how the relevant PO and PA texts articulate each feature of Engineering Education 5.0

4.3.1 Technical competency

Technical Competency highlights the integration of core engineering principles with modern technologies, such as data-handling and AI, to address current engineering challenges. This is evidenced in the EAIC, in which the core principles of technical knowledge, problem-solving, and design are embedded in the POs and PAs. However, their integration with modern technologies is less evident, as is now revealed in more detail.

Strong evidence in the EIAC's POs and PAs highlights the integration of fundamental principles with modern technologies to prepare engineers for innovation. This integration appears in PO1 (Knowledge and Understanding), PO4 (Investigation), and PA1 (Science and Mathematics), as well as PA3 (Software and Information Systems). PO1 focuses on combining engineering principles with proficiency in data science and analytics: "Knowledge and understanding of basic mathematics, sciences, data science, analytics, and other technologies related to the branch of engineering" (p.6). PO4 emphasises the use of technologies like data-handling and simulations in practice, requiring "The ability to conduct experiments and simulations and collate, analyse, present and interpret basic engineering datasets" (p.6). PA1 further reinforces the integration of fundamental engineering principles with modern technologies:

> *Engineers therefore also need the mathematical, analytical and data science tools to allow them to develop, validate, apply and adapt models of engineering components and systems in order to achieve optimal design (p.15)*

In this way, by emphasising mathematical and data science tools, PA1 supports the goal of equipping students to apply and adapt models to modern engineering challenges. Additionally, PA3 promotes the integration of modern technologies into the curriculum, particularly through data science and analytics, reflecting the focus on technical competency in Engineering Education 5.0:

> *Engineering students should, where appropriate, be taught the theory underlying those software and information systems which are of particular significance to engineering practice. This may include topics on data science and data analytics, as appropriate to the discipline (p.16)*

In contrast, while the POs and PAs mention data science and analytics, they do not address other emerging technologies such as AI or machine learning, which are vital for solving contemporary engineering challenges in Engineering Education 5.0 as outlined in Chapter Two. No guidance or requirements were found for students to gain skills in these advanced technologies.

PO3 (Design), PO2 (Problem Analysis), and PA4 (Creativity and Innovation) show evidence of preparing engineers to innovate. For example, PO3 highlights "the ability to contribute to the design of solutions to well-defined engineering problems" (p.6), a crucial skill for driving progress. PO2 further emphasises problem-solving, a key element of innovation, with the “ability to identify, formulate and analyse complex engineering problems” (p.12). Furthermore, PA4 fosters innovation by encouraging students to engage in research and design activities, as demonstrated by the following excerpt:

> *Research and design are central components of creativity and innovation. Research seeks to generate new knowledge which may lead, through the design process, to new products and systems (p.16)*

This focus on generating new knowledge aligns with the goals of Engineering Education 5.0 to prepare engineers who can lead technological advancements. PA2 also emphasises the importance of being thoroughly versed in the latest engineering technologies, supporting the preparation of engineers capable of using these technologies to innovate and solve real-world problems:

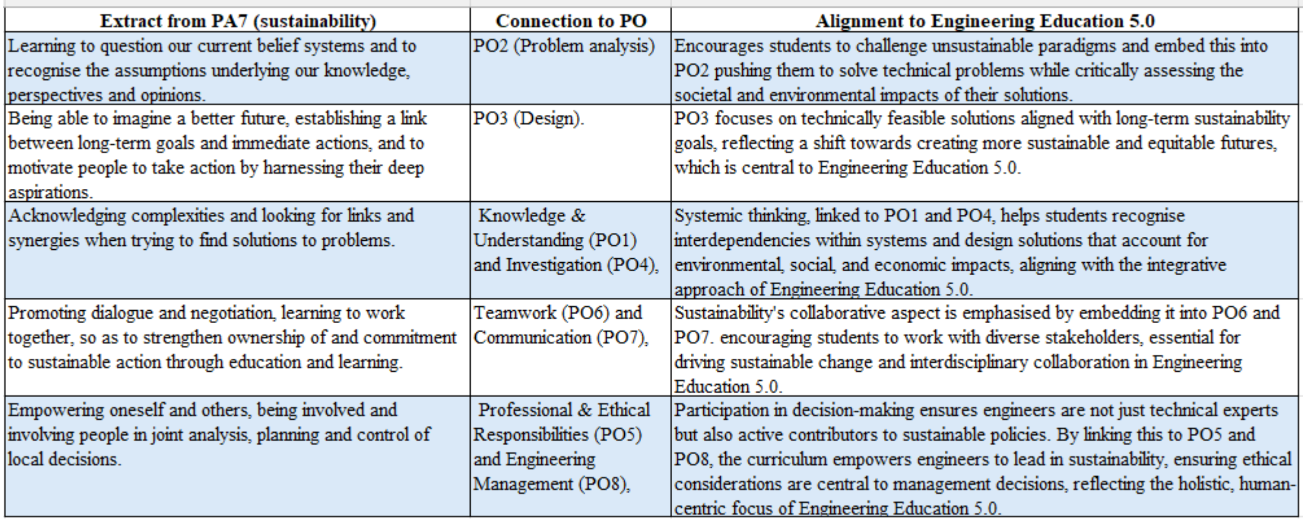
> *Students should be aware of the relative environmental impacts of the various technologies… Students' knowledge of the engineering technologies will be demonstrated in design projects, laboratory reports and projects that address engineering problems (p.15)*

In summary, the EIAC, as examined through the lens of the technical competency feature of Engineering Education 5.0, reveals a solid foundation in fundamental engineering principles, problem-solving and design. However, in this latest version of the EIAC, emerging technologies such as AI and machine learning are not explicitly addressed.

4.3.2 Sustainability

Sustainability is a core principle of Engineering Education 5.0, advocating for the adoption of principles to be ingrained as competencies within programmes. This emphasis is strongly reflected in the EIAC, particularly in the new PA7 (Sustainability), which takes a central role in emphasising the engineer's responsibility for "sustainability and climate change mitigation and adaptation" (p.17). It introduces concepts such as "net zero carbon, resource efficiency, circular economy, and whole-life cost" (p.17), aligning with the integrated approach to sustainability in Education 5.0. PA7 reflects progress towards embedding sustainability within Engineering Education 5.0 by incorporating principles and competencies needed to achieve the UNSDGs into the core curriculum. It threads these aspirations through all the POs, as exemplified in the extracts from p.17 (see Table 4-5).

Table 4-5: PA7 threaded through all POs



Extract from PA7 (sustainability)	Connection to PO	Alignment to Engineering Education 5.0
Learning to question our current belief systems and to recognise the assumptions underlying our knowledge, perspectives and opinions.	PO2 (Problem analysis)	Encourages students to challenge unsustainable paradigms and embed this into PO2 pushing them to solve technical problems while critically assessing the societal and environmental impacts of their solutions.
Being able to imagine a better future, establishing a link between long-term goals and immediate actions, and to motivate people to take action by harnessing their deep aspirations.	PO3 (Design).	PO3 focuses on technically feasible solutions aligned with long-term sustainability goals, reflecting a shift towards creating more sustainable and equitable futures, which is central to Engineering Education 5.0.
Acknowledging complexities and looking for links and synergies when trying to find solutions to problems.	Knowledge & Understanding (PO1) and Investigation (PO4),	Systemic thinking, linked to PO1 and PO4, helps students recognise interdependencies within systems and design solutions that account for environmental, social, and economic impacts, aligning with the integrative approach of Engineering Education 5.0.
Promoting dialogue and negotiation, learning to work together, so as to strengthen ownership of and commitment to sustainable action through education and learning.	Teamwork (PO6) and Communication (PO7),	Sustainability's collaborative aspect is emphasised by embedding it into PO6 and PO7. encouraging students to work with diverse stakeholders, essential for driving sustainable change and interdisciplinary collaboration in Engineering Education 5.0.
Empowering oneself and others, being involved and involving people in joint analysis, planning and control of local decisions.	Professional & Ethical Responsibilities (PO5) and Engineering Management (PO8),	Participation in decision-making ensures engineers are not just technical experts but also active contributors to sustainable policies. By linking this to PO5 and PO8, the curriculum empowers engineers to lead in sustainability, ensuring ethical considerations are central to management decisions, reflecting the holistic, human-centric focus of Engineering Education 5.0.

In the context of engineering Education 5.0, while there is some mention of environmental impacts, such as "design requirements arising from professional responsibilities towards people and the environment" (p.7), the EIAC does not explicitly address ecological considerations like reducing ecological footprints, preserving ecosystems, or nature-based design. This creates a gap in balancing technological advancements with ecological management. Despite the emphasis on sustainability awareness, there is a clear lack of focus on resource efficiency. For instance, PO1 highlights mathematical, scientific, and technological knowledge but does not explicitly address efficient resource use. Nor is there a specific focus on teaching students to incorporate resource efficiency into their technical solutions.

There is also limited emphasis in the POs on the broader societal and long-term environmental consequences of engineering decisions. While ethical responsibilities and professional duties are mentioned in PO5, the POs do not consistently stress the importance of considering long-term impacts on society and the environment. For example, PO4 covers the ability to investigate and solve engineering problems but does not mention long-term environmental and societal impacts. Similarly, PO8 focuses on organisational structures, resource management, and legal considerations but lacks detail on how engineering management should incorporate sustainability principles. There is no guidance on managing projects that balance technological progress with environmental stewardship and societal well-being.

Therefore, while the EIAC provides a foundation for integrating sustainability into engineering education, particularly through PA7, it falls short of the holistic approach outlined in Engineering Education 5.0. It lacks focus on resource efficiency, ecological integration, societal impacts, long-term environmental consequences, and a systemic approach to sustainability, presenting opportunities for improvement. Overall, the POs address sustainability in a fragmented way, rather than adopting a comprehensive approach that integrates ecological, societal, and technological elements. This is especially evident in PO2 (Problem Analysis), where, despite acknowledging professional responsibilities towards people and the environment, the interconnectedness of these factors is not fully considered.

4.3.3 Ethics and social impact

Engineering Education 5.0 places ethics and social impact at the centre of the educational framework, with particular emphasis on the ethical implications of technology. Unsurprisingly, due to the inclusion of PO5 (Ethics and Professional Responsibility), the EIAC reveals strong evidence of this feature.

The POs and PAs show differing degrees of alignment with the principles of Engineering Education 5.0. The results emphasise the importance of engineers understanding the broader environmental, social, and economic implications of their work, as reflected in a number of POs, highlighting the need to create solutions that balance technological advancement with societal needs. Additionally, several PAs point to the integration of ethical considerations across various aspects of engineering education.

First, there are several POs where ethics and social impact are evident, albeit to varying degrees. On the one hand, PO5 emphasises both the "understanding of and commitment to professional and ethical responsibilities towards people and the environment" and "an appreciation of the environmental, social, and economic impacts of their work, promoting sustainable development" (p.7). It also addresses the long-term impacts of decisions and the need to uphold honesty, integrity, and objectivity, directly supporting the holistic, human-centric approach of Engineering Education 5.0 as demonstrated in the following extract:

> *…an understanding and appreciation of the environmental, social and economic impacts of their decisions and to promote the principles and practices of sustainable development… knowledge and understanding of the importance of the engineer's role in society and the need to act with honesty, integrity and objectivity (p.9)*

On the other hand, PO3 (Design) highlights the importance of integrating ethical and social considerations into the design process, incorporating social responsibility into both design and problem analysis. It emphasises "the ability to consider design requirements arising from professional responsibilities towards people and the environment" (p.8). It links professional responsibilities with problem-solving methodology, supporting ethical analysis in engineering.

While PO3 and PO5 show a strong commitment to integrating ethics and social responsibility, there are areas for improvement, particularly in expanding the ethical and social dimensions of technical knowledge, problem-solving, and management. For instance, PO1 (Knowledge and Understanding) centres primarily on technical knowledge, with limited reference to its ethical application. Similarly, PO8 (Engineering Management) addresses management and legal principles but offers little guidance on ethical decision-making or the social responsibilities involved in managing projects. To align more fully with the principles of Engineering Education 5.0, there could be a clearer emphasis on managing projects and resources ethically, with explicit attention to their societal and environmental impacts.

Although PO4 (Investigation) emphasises critical evaluation with "the ability to critically evaluate current problems and new insights" (p.10), it could be expanded to include the ethical implications and social responsibilities tied to investigating and solving engineering problems.

Second, ethics and social responsibility are woven into several PAs, reflecting a shift towards integrating the societal impact of engineering. PA1 (Science and Mathematics), while focused on providing foundational tools, also encourages critical reflection on existing theories and assumptions.

> *Students should be encouraged to reflect upon standard theories, and their inherent assumptions, and, where necessary, adapt them to a range of engineering problems (p.15)*

This focus on reflection and adaptation aligns with engineers' ethical duty to question the status quo and consider the wider societal and environmental impacts of applying scientific and mathematical knowledge. It fosters a mindset where technical solutions are evaluated not only for efficiency but also for their ethical implications (Marin *et al.*, 2025). PA2 (Discipline-specific Technology) and PA3 (Software and Information Systems) stress the importance of understanding the environmental impacts of technology and the need for multidisciplinary collaboration in the responsible use of software and information systems:

> *Students should be aware of the relative environmental impacts of the various technologies... Students should also have the opportunity to become involved in multidisciplinary projects which require them to draw upon technologies outside their immediate area of interest. (p.15)*

> *They should know how to apply, to adapt and, where necessary, through data exchange, to integrate industry–standard software tools and information systems. (p.16)*

By recognising environmental impacts, these extracts highlight engineers' responsibility to develop technologies that minimise environmental harm.

Ethics and social responsibility are embedded in the creative process in PA4 (Creativity and Innovation), particularly through Universal Design and the evaluation of new ideas, as shown in this extract:

> *Students should have an understanding of the application of Universal Design as the design and composition of an environment so that it can be accessed, understood and used to the greatest extent possible by all people regardless of their age, size, ability or disability… Students should also gain some proficiency in the principles and application of project management, legal frameworks and client management as appropriate to their discipline. (p.16)*

Universal Design is closely linked to social responsibility, promoting inclusive and accessible engineering solutions for all.

PA5 (Engineering Practice) demonstrates a utilitarian approach to ethics, advocating that students “deal with technical uncertainty and have awareness of codes of practice and the regulatory framework” (p.16).

Finally, PA6 (Societal and Business Context) and PA7 (Sustainability) explicitly address engineers' social responsibility by fostering awareness of the societal and commercial contexts in which they operate, as shown in these extracts:

> *Programmes need to develop an awareness of the social and commercial context of the engineer’s work… They should be given ample opportunity to analyse and discuss the ethical consequences of their decisions. (p.15-16)*
>
> *Students need to be familiar with the impact of their work on the three pillars of sustainability (environmental impact, social impact and economic impact) and should aspire to be leaders in engineering climate action. (p.16)*

Linking engineering practice to ethical decision-making helps ensure that students understand the societal impact of their work. This connection is also made explicit in PA7, which emphasises the engineer’s role in promoting sustainability and tackling global challenges. It reflects the ethical responsibility of engineers to contribute to sustainable development, an essential aspect of social responsibility in Engineering Education 5.0.

The results reveal that ethics and social responsibility are embedded throughout the EIAC, fostering technical proficiency while cultivating ethical awareness and social responsibility, preparing graduates for the moral and societal challenges in their careers. However, some aspects, particularly the integration of societal elements, balancing technological advancement with environmental management, and emphasising resource efficiency and long-term impacts, are underemphasised or not explicitly addressed.

4.3.4 Collaboration

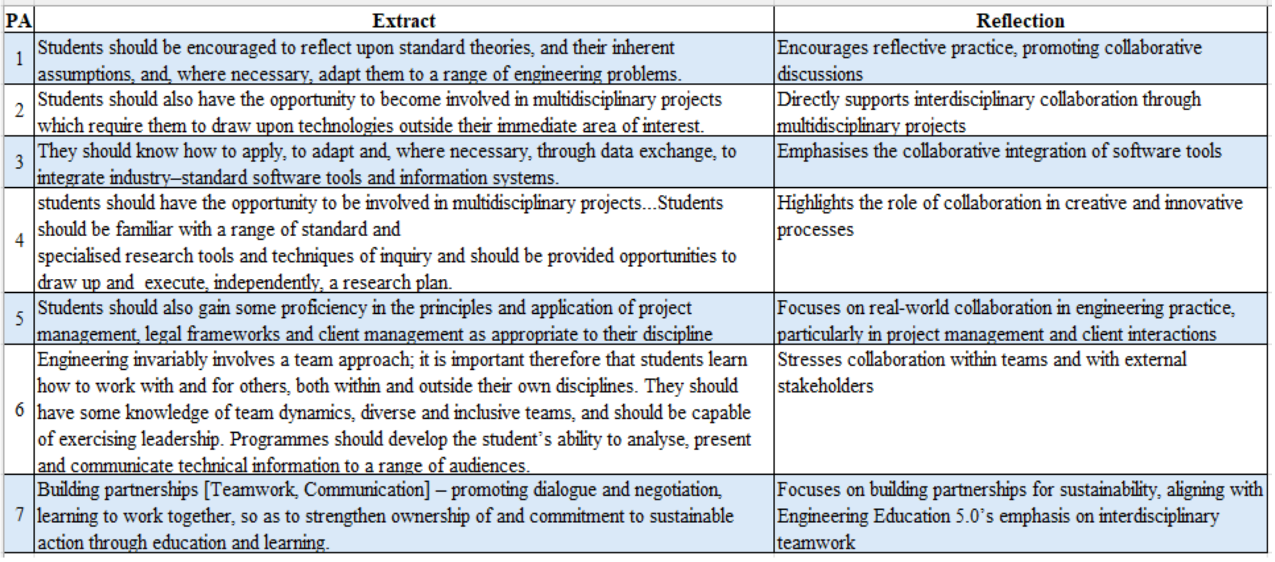
In Engineering Education 5.0, collaboration transcends technical disciplines, fostering interdisciplinary and inclusive approaches. The results from the EIAC show that collaboration is strongly embedded within the teamwork element of PO6 (Teamwork and Lifelong learning) and PO7 (Communication), in particular emphasising interdisciplinary teamwork and stakeholder engagement. In contrast, for instance, PO8 (Engineering Management) does not explicitly reference collaboration; its focus is on management structures, resources, and governance.

The results provide strong evidence of collaboration in the POs and PAs, particularly through a focus on diverse, inclusive teams and the integration of societal and business contexts, promoting broader stakeholder engagement. Selected extracts supporting this, as well as areas where the POs and PAs lack emphasis on collaboration, are now presented:

- PO6 emphasises the importance of interdisciplinary collaboration, highlighting teamwork across multiple disciplines, noting, “The ability to work effectively independently and in diverse and inclusive teams and to prepare for lifelong learning” (p. 7). However, it does not explicitly mention interdisciplinary teamwork or the integration of diverse disciplines, a key element of Engineering Education 5.0.
- PO7 underscores the development of communication skills essential for collaboration. “The ability to communicate effectively on engineering activities to diverse audiences… the ability to design and implement effective communication strategies in order to create deeper understanding and maximum impact on a given audience… the ability to communicate effectively in public, national, international and multicultural contexts” (p.11). This ensures that engineers can work effectively in global teams and engage with a wide range of stakeholders.
- PO3 emphasises collaboration in the design processes, encouraging engagement across disciplines to develop innovative solutions; “the ability to design innovative solutions such as novel systems, components or processes, involving other disciplines as appropriate” (p.10). However, while PO3 acknowledges technological advancements, it could better emphasise the collaborative efforts required to stay current with these changes.
- PO4 reflects the collaborative nature of research, expecting engineers to engage with experts from other fields: “the ability to incorporate aspects of engineering outside the branch of engineering and consult and work with experts in other fields” (p.12). This interdisciplinary approach ensures that research is comprehensive, considering societal and environmental impacts.

Collaboration is also threaded throughout the PAs (see Table 4-6), by inter alia encouraging reflective practice, promoting collaborative discussions, emphasising the collaborative integration of software tools, and focusing on real-world collaboration in engineering practice.

Table 4-6: Collaboration in the PAs



PA	Extract	Reflection
1	Students should be encouraged to reflect upon standard theories, and their inherent assumptions, and, where necessary, adapt them to a range of engineering problems.	Encourages reflective practice, promoting collaborative discussions
2	Students should also have the opportunity to become involved in multidisciplinary projects which require them to draw upon technologies outside their immediate area of interest.	Directly supports interdisciplinary collaboration through multidisciplinary projects
3	They should know how to apply, to adapt and, where necessary, through data exchange, to integrate industry–standard software tools and information systems.	Emphasises the collaborative integration of software tools
4	students should have the opportunity to be involved in multidisciplinary projects...Students should be familiar with a range of standard and specialised research tools and techniques of inquiry and should be provided opportunities to draw up and execute, independently, a research plan.	Highlights the role of collaboration in creative and innovative processes
5	Students should also gain some proficiency in the principles and application of project management, legal frameworks and client management as appropriate to their discipline	Focuses on real-world collaboration in engineering practice, particularly in project management and client interactions
6	Engineering invariably involves a team approach; it is important therefore that students learn how to work with and for others, both within and outside their own disciplines. They should have some knowledge of team dynamics, diverse and inclusive teams, and should be capable of exercising leadership. Programmes should develop the student's ability to analyse, present and communicate technical information to a range of audiences.	Stresses collaboration within teams and with external stakeholders
7	Building partnerships [Teamwork, Communication] – promoting dialogue and negotiation, learning to work together, so as to strengthen ownership of and commitment to sustainable action through education and learning.	Focuses on building partnerships for sustainability, aligning with Engineering Education 5.0's emphasis on interdisciplinary teamwork

Collaboration is found to be embedded in the EIAC, echoing Engineering Education 5.0. While several POs and PAs highlight interdisciplinary teamwork and stakeholder engagement, they could place greater emphasis on interdisciplinary problem-solving and adapting to technological advancements to better align with the collaborative, real-world focus of Engineering Education 5.0.

4.3.5 Educational approach

Engineering Education 5.0 advocates for adaptive, lifelong learning that integrates individual needs and societal changes. The EIAC reveals strong evidence of continuous learning and inclusivity but provides less emphasis on personalised education and adaptability to societal changes. Strong evidence was found in the POs and PAs reflecting continuous learning, lifelong learning, and adaptability. Less evident are flexibility, personalisation, and inclusive learning environments.

Several POs and PAs reflect continuous learning, lifelong learning, adaptability, personalisation, and inclusivity in education. First, PO6 (Teamwork and Lifelong Learning) highlights the importance of lifelong learning across all levels of engineering education. Graduates are expected to "recognise the need for and the ability to undertake self-directed continuing professional development (CPD)" (p.7), which is crucial for maintaining an adaptable workforce in line with technological and societal advancements. Similarly, PA6 (Societal and Business Context) emphasises continuous learning, encouraging students to take responsibility for their ongoing education, aligning with Engineering Education 5.0's lifelong learning focus as demonstrated in the following extract from PA6:

> *The importance of students identifying their own learning needs, and exercising responsibility for their own continuing professional development, should be stressed (p.17)*

Second, PO2 (Problem Solving) emphasises adaptability by expecting graduates to "integrate knowledge, handle complexity, and formulate judgments with incomplete or limited information" (p.10), reflecting the need for flexibility in dynamic environments. Similarly, PO3 requires engineers to design innovative solutions for "unfamiliar, ill-defined problems" (p.12), aligning with Engineering Education 5.0's focus on adaptability, preparing graduates for emerging challenges and new technologies. This adaptability is further evident in PA4 (Creativity and Innovation) and PA7 (Sustainability), where students are encouraged to solve unsolved problems, innovate, and adapt to new challenges. Systemic thinking is also stressed, requiring students to adapt to complex, interconnected systems, which is crucial for addressing modern engineering challenges.

> *Students should be encouraged to think beyond the obvious and routine, and be given opportunities to face the challenges of previously unsolved problems… acknowledging complexities and looking for links and synergies when trying to find solutions to problems (p.17)*

Although the POs and PAs highlight adaptability in technical challenges, there is limited evidence of the flexibility needed to respond to rapidly changing societal needs, a key aspect of Engineering Education 5.0.

Third, personalisation of education is implicitly supported by a diverse range of POs, which cater to different career stages and specialisations, from Engineering Technicians to Chartered Engineers. Each level has tailored outcomes that build on prior knowledge, allowing for an individualised learning path. PO6 also highlights the importance of engineers working in "diverse and inclusive teams" (p.7), suggesting an educational environment that adapts to learners' unique backgrounds and career goals. PA1 (Science and Mathematics) and PA4 (Creativity and Innovation) show flexibility in the depth of study based on accreditation standards and chosen disciplines, allowing for a more personalised educational experience. Additionally, the opportunity for students to independently execute research plans supports personalised learning by enabling them to focus on areas of personal and professional interest:

> *Students should be familiar with a range of standard and specialised research tools and techniques of inquiry and should be provided opportunities to draw up and execute, independently, a research plan (p.16)*

However, the criteria do not explicitly address the personalisation of education to cater to individual needs and career goals. Engineering Education 5.0 stresses the importance of tailoring education to each student, adapting to diverse learning styles and aspirations. For instance, while PO6 (Teamwork and Lifelong Learning) mentions lifelong learning, it does not specify how education will be personalised to suit different learning paths or career goals.

Lastly, inclusion is briefly acknowledged in PO5, which emphasises understanding "the importance of equality, diversity, and inclusion" (p.7), and in PA6 (Societal and Business Context), which highlights teamwork in diverse, multidisciplinary environments:

> *Engineering invariably involves a team approach; it is important therefore that students learn how to work with and for others, both within and outside their own disciplines. They should have some knowledge of team dynamics, diverse and inclusive teams, and should be capable of exercising leadership (p.17)*

Overall, the POs largely overlook how to create a fully inclusive learning environment that actively supports diverse backgrounds, learning styles, and needs. Engineering Education 5.0 advocates for an inclusive, equitable education system with equal access for all students. However, the criteria do not specifically address how learning environments will be adapted to accommodate students with different abilities, backgrounds, or learning preferences. Therefore, while the criteria do address some continuous learning and inclusivity, they are notably silent or underdeveloped in areas crucial to the educational approach of Engineering Education 5.0. These gaps include the personalisation of education, the need for adaptability to societal changes, and the creation of truly inclusive learning environments.

4.3.6 Global and cultural perspectives

Global and cultural perspectives in Engineering Education 5.0 emphasise expanding students' understanding of engineering in a global context. This includes preparing graduates to engage with the international engineering community, communicate across cultures, and address global engineering challenges. To this end, the EIAC highlights the importance of international agreements, addressing global environmental issues, and recognising cultural differences. Overall, the POs and PAs reveal different levels of evidence on the global implications of their work, global and cultural insights, communication and collaboration across cultures, and interdisciplinary collaboration.

First, when it comes to global context and sustainability**,** PO5 (Professional and Ethical Responsibilities) and PO7 (Communication) underscore the need for engineers to consider the global implications of their work, particularly regarding sustainability. Notably, PO7 is the only PO with explicit international or multicultural language

> *…an understanding and appreciation of the environmental, social and economic impacts of their work and to promote the principles and practices of sustainable development (p.7)*

> *…the ability to communicate effectively in public, national, international and multicultural contexts (p.11)*

PA6 (Societal and Business Context) emphasises understanding the broader societal context, including multicultural considerations and global constraints. At the same time, PA7 (Sustainability) introduces students to global frameworks like the UN Sustainable Development Goals (SDGs), broadening their perspectives.

Second, while the POs emphasise communication and teamwork, they do not explicitly address global and cultural insights. For example, PO1 (Knowledge and Understanding) focuses on technical knowledge but does not require an understanding of its global applications. Similarly, PO2 (Problem Analysis) mentions environmental responsibilities but lacks emphasis on global perspectives, such as international regulations or supply chains. PA1 (Science and Mathematics) and PA2 (Discipline-specific Technology) focus on technical skills without considering how they vary across cultures or regions.

Third, PO6 (Teamwork and Lifelong Learning) and PO7 (Communication) stress the importance of working in diverse teams but do not fully address cross-cultural communication. However, PO7 is not explicit about preparing students to navigate cultural differences effectively

Finally, in preparing students for the international engineering community, PO4 (Investigation) prepares students to address wider engineering challenges and engage in interdisciplinary collaboration:

> *…the ability to incorporate aspects of engineering outside the branch of engineering and consult and work with experts in other fields (p.10)*

PA6 (Societal and Business Context) and PA7 (Sustainability) emphasise communication and global sustainability goals, crucial for contributing to the international engineering community as illustrated in the extracts below:

> *…the student's ability to analyse, present and communicate technical information to a range of audiences (p.17)*
>
> *Students should also develop competences for achieving the SDG (p.17)*

The EIAC, therefore, reflects the global and cultural aspects of Engineering Education 5.0, recognising the global impact of engineering, effective cross-cultural communication, and collaboration in the international engineering community. However, a more explicit focus on global cultural insights and the challenges of working in international contexts is needed. PO8 (Engineering Management) and PA3 (Software and Information Systems) lack emphasis on global management issues and international standards. PA5 (Engineering Practice) could better prepare students for global supply chains and international project management, and PA2 (Discipline-specific Technology) overlooks global technology trends and international research.

4.3.7 Holistic & human-centric

Engineering Education 5.0 focuses on integrating technical skills with a deep understanding of the human context, aiming to create technology that benefits humanity and enhances the quality of life. The EIAC emphasises EDI and recognises the impact of engineering decisions on people. Across the POs and PAs, evidence to support this approach was found with respect to a focus on the human context and ethical responsibilities, integration of technical skills with human-centric design, challenges of ensuring equal access, and holistic problem-solving approach.

First, PO5 reflects the holistic focus by ensuring that engineers consider the human context and ethical responsibilities of their work, promoting technology that enhances life quality and sustainability; as illustrated in the following extract, this human-centric approach advocates for inclusive practices in engineering:

> *...an understanding and appreciation of the environmental, social and economic impacts of their work and to promote the principles and practices of sustainable development ...equality, diversity and inclusion, and their impact on professional practice (p.9)*

Second, PO3 (Design) connects technical design skills with human-centric considerations, highlighting the importance of creating engineering solutions that are both socially responsible and environmentally sustainable. This is reflected in the outcome: "the ability to consider design requirements arising from professional responsibilities towards people and the environment" (p.8). Similarly, PA6 (Societal and Business Context) and PA7 (Sustainability) reinforce this human-centric perspective by emphasising the role of engineering in serving communities and addressing societal needs. As stated, "Engineering is directed to developing, providing and maintaining infrastructure, goods, systems and services for industry and the community" (p.16), and "Students… should aspire to be leaders in engineering climate action" (p.17).

These statements support the vision of Engineering Education 5.0 by underscoring the importance of considering the broader impact of engineering work on society and the environment. They encourage students to design solutions that go beyond technical functionality to influence human well-being positively and contribute to global sustainability.

Third, when it comes to challenges of ensuring equal access and accommodating diverse learning styles, PO6 (Teamwork and Lifelong Learning) highlights the challenge of accommodating diverse learning styles by promoting teamwork in inclusive settings and emphasising continuous learning, which is critical for adapting to different educational needs: “The ability to work effectively independently and in diverse and inclusive teams” (p.7). PO7 (Communication) proposes that engineering solutions are accessible to all, regardless of cultural or educational background, thus addressing the need for inclusivity in the dissemination of technological knowledge. PA4 (Creativity and Innovation) support this approach for equality:

> *Students should have an understanding of the application of Universal Design as the design and composition of an environment so that it can be accessed, understood and used to the greatest extent possible by all people regardless of their age, size, ability or disability (p.16)*

This extract from PA4 directly aligns with the human-centric focus of Engineering Education 5.0 by advocating for designs that are inclusive and beneficial to all, improving the quality of life across diverse populations.

Fourth, PO2 (Problem Analysis) supports a holistic approach by integrating problem-solving with an understanding of “basic problem-solving techniques and the role of professional responsibilities towards people and the environment" (p.6), encouraging engineers to develop solutions that are beneficial on a broad scale.

While the EIAC, through the POs and PAs, emphasises the human context in professional responsibilities and design, there is less focus on developing technology aimed at directly improving quality of life. Specific references to designing for accessibility, usability, or the needs of vulnerable populations are limited. The POs and PAs mention inclusivity and diversity in teamwork and communication. Additionally, the POs and PAs provide limited guidance on ensuring equal access to learning opportunities, particularly concerning technological resources and infrastructure, as highlighted in Engineering Education 5.0.

4.3.8 How does the 2021 EIAC represent Engineering Education 5.0?

The updated 2021 EIAC demonstrates meaningful alignment with the principles of Industry 5.0 through the lens of Engineering Education 5.0, particularly in areas such as ethics, sustainability, and collaboration, as shown in Table 4-7

Table 4-7: Summary of Phase 2 across POs and Pas

Feature of Engineering Education 5.0	Relevant POs	Relevant PAs
Technical Competency	PO1 (Knowledge & Understanding); PO2 (Problem Analysis); PO3 (Design); PO4 (Investigation)	PA1 (Science & Mathematics); PA2 (Discipline-specific Technology); PA3 (Software & Information Systems); PA4 (Creativity & Innovation)
Sustainability	PO2 (Problem Analysis); PO3 (Design); PO5 (Ethics & Professional Responsibility); PO8 (Engineering Management)	**PA7 (Sustainability)**
Ethics & Social Impact	PO3 (Design); PO4 (Investigation); PO5 (Ethics & Professional Responsibility); PO8 (Engineering Management-weak on ethics)	PA1 (Science & Maths); PA2 (Technology); PA3 (Software & IS); PA4 (Creativity & Innovation-Universal Design); PA5 (Engineering Practice); PA6 (Societal & Business Context); PA7 (Sustainability)
Collaboration	PO3 (Design-multidisciplinary solutions); PO4 (Investigation-consultation with experts); PO6 (Teamwork & Lifelong Learning); PO7 (Communication)	PA6 (Societal & Business Context)
Educational Approach	PO2 (Problem Analysis-complexity); PO3 (Design-unfamiliar problems); PO6 (Lifelong Learning, inclusive teams); PO7 (Communication-inclusivity)	PA1 (Science & Maths-depth flexibility); PA4 (Creativity & Innovation-unsolved problems, research autonomy); PA6 (CPD responsibility, teamwork in diverse groups); PA7 (systemic thinking for sustainability)
Global & Cultural Perspectives	PO5 (Ethics-sustainability); PO7 (Communication-international, multicultural contexts)	PA6 (multicultural context); PA7 (SDGs, global sustainability)
Holistic & Human-Centric	PO2 (Problem Analysis-responsibilities to people/environment); PO3 (Design-human/social factors); PO5 (Ethics-EDI, impacts of decisions); PO6 (Inclusive teamwork); PO7 (Accessible communication)	PA4 (Universal Design); PA6 (Engineering as community service); PA7 (Climate action leadership)

Core features like professional responsibility, interdisciplinary teamwork, and the integration of sustainability are well represented through specific POs and PAs. However, the evidence of the seven features of Engineering Education 5.0 remains uneven. While there is progress in integrating contemporary technologies such as data analytics, there is a lack of explicit reference to advanced technologies, including AI. Similarly, although sustainability is formally introduced through PA7, its fragmented treatment across the framework limits its full systemic impact. The human-centric and ethical dimensions are strong, especially in PO5, though gaps remain in linking ethics to technical and managerial decision-making.

Collaboration is clearly embedded, but the potential for deeper interdisciplinary engagement and stakeholder involvement is underdeveloped. Educational approaches supporting lifelong learning and inclusivity are present; however, the criteria fall short in personalising learning and fully addressing diverse learner needs. Lastly, global and cultural perspectives are acknowledged but not comprehensively addressed, leaving room to improve graduate preparedness for international and multicultural work environments. Overall, the EIAC marks a significant step toward Engineering Education 5.0 but would benefit from more explicit, systemic, and integrated treatment of its core features to fully realise the framework's transformative vision, as is discussed in Chapter Five.

4.4 POs in SARs and Engineering Education 5.0

This section presents results of the analysis of how accreditation expectations are discursively articulated and locally enacted within one HEI's Self-Assessment Reports (SAR), specifically, the programme outcome (PO) texts in order to address sub-research question three (How is Industry 5.0 represented in the programme outcomes in the self-assessment reports produced as part of accreditation within a HEI in Ireland?). Chapter Three described the accreditation process, specifically highlighting the role of SARs in this process. The relevance of the POs as the focus of analysis, as well as a breakdown of the details of each SAR under review, was also explained, along with the approach adopted to analysis. In this section, the results of the analysis of the PO texts examined against the seven features of the Engineering Education 5.0 model are presented. The results are synthesised and summarised in Table 4-8.

Table 4-8 Summary of Phase Three results

Feature of Engineering Education 5.0	Key Interpretations & Tensions
Technical Competency	Emphasis on digital literacy and tools; Limited evidence on AI readiness
Sustainability	Increasingly embedded; often siloed in modules
Ethics & Social Impact	Embedded through projects; variable integration
Collaboration	Evident in capstone/project work; Less emphasis on external collaboration
Educational Approach	Strong support for CPD; personalised learning rarely documented
Global & Cultural Perspectives	Noted through mobility; limited discussion of cultural competence
Human-Centricity	Support for Universal Design; uneven EDI emphasis

Section 4.4.1 provides the contextual background for the analysis of the POs submitted by the HEI in its SARs. Sections 4.4.2- 4.4.8 then present the results for each of the seven Engineering Education 5.0 features in turn.

4.4.1 Contextualising the results

Prior to examining the individual features of Engineering Education 5.0 in the POs, it was important to reflect upon and acknowledge contextual contingency across the 16 SAR documents reviewed. While the overall language and format of the POs were consistent, some programmes demonstrated a significantly higher degree of alignment with Engineers Ireland's SAR requirement than others, as outlined in Section 3.3.2.3 (p.64).

There was a marked increase in the volume and sophistication of evidence presented in SARs associated with NFQ Level 9 (Chartered Engineer) programmes compared to those at Levels 7 and 8. For instance, level 9 programmes more consistently addressed complex engineering problems, integrated sustainability frameworks (e.g. UNSDGs, life-cycle analysis), and demonstrated higher-level ethical and social reflection. These documents also tended to show stronger alignment with the Educational Approach feature, particularly in self-directed learning and research-led practice.

For example, Documents 3, 6, 9, and 12 were frequently cited in the extracts, offering rich, multi-level descriptions across multiple POs. Conversely, Documents 4, 8, and 13 contained more generalised descriptions, leading to fewer citations. This variability is not interpreted as a lack of compliance with accreditation standards but rather may reflect differing levels of engagement with or articulation of the POs.

In a similar fashion to the previous sections, results relating to each of the seven features of Engineering Education 5.0 are considered separately. Within the following narrative, relevant extracts from the POs contained in the SARs are presented.

The extracts from the SARs included as supporting evidence in this section have been carefully selected and are representative of the descriptions generated by the programme boards in the POs. To avoid redundancy in the presentation of results and to provide sufficient balance and breadth, a select number of the most relevant data extracts are published to illustrate each one. A summary of the relationship between the SARs submitted and the documents containing the POs subsequently analysed and numbered 1-16 was explained in Chapter Three.

4.4.2 Technical competency

Technical competency, a core feature of Engineering Education 5.0, was persistently articulated across all SARs. As expected, it was most prominent in PO1–PO4, which reflect the technical core of engineering programmes. However, evidence was also threaded through non-technical POs (PO5–PO8), illustrating how technical skills are integrated across broader professional attributes.

As illustrated in Table 4-9, strong evidence was found in core technical outcomes (PO1-PO4), while more limited but relevant instances of integration were observed in professional skills domains (PO5-PO8). The results of analysis from each of the eight POs show how technical competency is present across NFQ levels 7-9. Sections 4.4.2.1-4.4.2.4 present the results of the technical POs, with section 4.4.2.5 laying out those of the non-technical POs.

Table 4-9 Technical competency matrix (POs x NFQ Level)

Programme Outcome		NFQ 7	NFQ 8	NFQ 9
PO1	Knowledge & Understanding	🟩	🟩	🟩
PO2	Problem Analysis	🟧	🟩	🟩
PO3	Design	🟧	🟩	🟩
PO4	Investigation	🟧	🟩	🟩
PO5	Professional & Ethical Resp	🟧	🟧	🟧
PO6	Teamwork and LLL	🟦	🟦	🟧
PO7	Communication	🟦	🟧	🟧
PO8	Engineering Management	🟦	🟦	🟧

🟩	strong evidence
🟧	moderate evidence
🟦	limited evidence

4.4.2.1 Technical competency in PO1 (Knowledge and Understanding)

Technical competency in PO1 was strongly evidenced across all documents and educational levels. The results show clear progression from foundational mathematical skills to advanced analytical and software-based engineering competencies. The results show clear progression from foundational mathematical skills at NQF Level 7 to advanced analytical and software-based engineering competencies at NQF Level 9, as shown in the extracts below. At Level 7, the texts position learners as developing proficiency in mathematical and scientific fundamentals. Programmes also embed applied statistics early on. At level 8 there is a shift toward applied analytics, and domain-specific knowledge is evident Finally, at Level 9, learners engage in sophisticated, independent analysis. However, despite strong evidence for data science and modelling, no direct references to AI were found across any PO1 entries at Level 9.

- **NFQ Level 7**

> *gain knowledge on fundamentals areas in mathematics such as arithmetic, algebra and trigonometry. The module builds an understanding of core skills to ensure all students have a solid mathematical foundation before moving onto more advanced maths modules in later year (Doc 1, NFQ 7).*
>
> *Students are exposed to a broad range of mathematical, scientific and engineering knowledge, with a focus on engineering applications using statistical software (Doc 5, NFQ 7).*

- **NFQ Level 8**

> *The key probability distributions are explored along with statistical inference and learners use the statistical package Minitab for analysis. Regression and correlation analysis are also presented (Doc 6, NFQ 8).*

- **NFQ Level 9**

  the students develop a deeper knowledge and understanding of a wide range of engineering principles, materials, processes and emerging technologies. Design for assembly (DFA), design for manufacture (DFM) and failure mode & effect analysis (FMEA) require critical thinking and integration of information across materials, manufacturing and design domains (Doc 9, NFQ 9).

  Emphasis is placed on the limitations of sensing systems particularly the limitation of theoretical approach when applied to an actual system. Both the disruption and advantages of Industry 4.0 are explored (Doc 8, NFQ 9).

4.4.2.2 Technical competency in PO2 (Problem Analysis)

PO2 demonstrates a structured evolution in problem-solving competencies, progressing from conceptual analysis and formulaic approaches at Level 7, to the integration of digital systems and modelling at Level 8, where data analytics, mathematical modelling, and justification of solutions are emphasised, and culminating at Level 9 in advanced diagnostic reasoning and systems-level analysis supported by simulations and specialised software.

- **NFQ Level 7**

  learners are expected to progress from classification and categorisation of a problem through accumulation of necessary information, and formulation of an approach to competent analysis and solution. The progress through the stages of these two programmes is reflected in the range and complexity of the problems encountered (Doc 5, NFQ 7).

- **NFQ Level 8**

  Introduces students to the application of digital automation systems to solve engineering problems with real-time feedback mechanisms (Doc 10, NFQ 8).

  students are required to analyse an engineering problem and present their analysis, justifying any decisions made as part of that analysis (Doc 11, NFQ 8).

  Analysis of engineering problems requires the development of mathematical models and also instrumented physical models to monitor the performance of a system/component (Doc 2, NFQ 8).

- **NFQ Level 9**

  Data and results must be analysed using the appropriate mathematical and statistical techniques and all information attained should be analysed in relation to the projects context and should be synthesised relative to the constraints and limitations of the project and experimental design (Doc 3, NFQ 9).

  Learners are expected to progress from classification and categorisation of a problem through accumulation of necessary information, formulation of approach to competent analysis and solution (Doc 8, NFQ 9).

This clear and structured evolution in the development of problem-solving competencies affirms strong alignment with the Engineering Education 5.0 emphasis on complex systems thinking and structured, data-informed analysis. At the higher levels, the emphasis on simulation, diagnostics, and contextual synthesis illustrates how learners are being prepared to operate in dynamic, technology-rich environments where problem-solving requires critical judgment and systems awareness as well as technical accuracy.

4.4.2.3 Technical competency in PO3 (Design)

PO3 provides consistent evidence of design-related technical competency. Progression through NFQ levels shows a deliberate shift from introductory design principles and CAD-based modelling at Level 7, to the integration of analytical tools and experimental methods at Level 8 and culminating at Level 9 in system-level experimentation and optimisation informed by advanced simulations and prototyping as illustrated by the following extracts.

- **NFQ Level 7**:

> *...assess power converters, and their impact on power systems and can contribute to the design of converters for common applications (Doc 9, NFQ 7).*
>
> *The ability to manipulate & analyse 3D models with various CAE tools and to capture design intent with parametric tools allows the students to develop better techniques to design, visualise and simulate their ideas leading them to create and explore more innovative concepts (Doc 12, NFQ 7).*
>
> *...develops competence in the application of up-to-date engineering tools skills to progress the design...using industry standard software (Doc 1, NFQ 7).*

- **NFQ Level 8**

> *Advanced features of three-dimensional design software for rapid generation of design features along with design for failure and factors of safety are incorporated (Doc 2, NFQ 8).*
>
> *They learn to use tools such as Excel (recycle calculations and WhatIf analysis and AspenPlus (Doc 4, NFQ 8).*
>
> *Learners are introduced to experimental processes and data collection in laboratory work in the early stages of the programme (Doc 6, NFQ 8).*

- **NFQ Level 9**

> *...design simple circuits with user-specified performance and in later years students assess power converters and their impact on power systems and the design of converters for common applications (Doc 10, NFQ 9).*
>
> *Learners undertake laboratory experiments to prove concepts in the different engineering technology streams informing the students about validation and performance evaluation (Doc 7, NFQ 9).*

> *Learners are introduced to experimental processes and data collection throughout the programme (Doc 8, NFQ 9).*

This trajectory highlights the development of practical, transferable skills essential for Engineering Education 5.0, with design thinking increasingly reinforced through digital tools that mirror contemporary engineering practice.

4.4.2.4 Technical competency in PO4 (Investigation)

PO4 provides strong evidence of investigative skill development, particularly in the use of instrumentation, analytical tools, and research practices. Progression across NFQ levels shows increasing autonomy, sophistication in data analysis, and engagement with real-world tasks. At Level 7, programmes emphasise measurement, signal processing, and circuit simulation. At Level 8, students undertake structured investigations through prototype development and data interpretation. By Level 9, they engage in independent research and redesign activities, drawing on advanced methods and emerging technologies as shown in the extracts below:

- **NFQ Level 7**:

> *This requires the use of instrumentation and the development of testing strategies. Sensors, signal processing, data capture and data analysis are important elements of this process (Doc 1, NFQ 7).*
>
> *Make meaningful measurements on electrical circuits and interpret the results to determine any faults present (Doc 12, NFQ 7).*
>
> *Proteus, LTSpice and Vivado circuit simulation tools allow both functional operation and mechanical 3D verification of circuits (Doc 15, NFQ 7).*

- **NFQ Level 8**:

> *...prototype developments are enabled by investigation through advanced computer aided design software tools including Autodesk Inventor, Autodesk add-on Finite Element package, ANSYS. In electronic and control circuit design and development application such as TinkerCAD aid in virtual prototype investigation (Doc 2, NFQ 8).*
>
> *Analysis and interpretation of data is a key element of this project, and students are assessed on their experimental work, simulation work, analysis of data and the validity of their conclusion. (Doc 4, NFQ 8).*
>
> *...emphasises the development of various skills and competences related to categorisation of a problem, its investigation and formulation of competent analysis to arrive at a solution (Doc 6, NFQ 8).*

- **NFQ Level 9**:

> *Redesign of components for optimisation requires investigation through literature reviews of current and emerging technologies and critical interrogation of databases (Doc 3, NFQ 9).*

> *The investigative and research process for the acquisition of new knowledge is developed to a high level in the final year of the programme (Doc 7, NFQ 9).*
>
> *Students are encouraged to identify unfamiliar problems within a single area of engineering, and to use and develop new technologies to enable solutions to be found (Doc 8, NFQ 9).*

This evolution demonstrates a shift from structured verification at Level 7 to research-based project work at Level 9. The use of diagnostic tools, experimental software, and prototyping aligns with the investigative dimension of Engineering Education 5.0, though explicit evidence of AI or data-driven innovation remains limited.

4.4.2.5 Technical competency in non-technical POs (PO5-8)

While POs 5-8 are not primarily technical in nature, the results revealed notable instances where technical skills were embedded within broader professional competencies. These results highlight the interdisciplinary integration encouraged by Engineering Education 5.0, where technical fluency supports ethics, communication, teamwork, and management practices.

- **PO5 Ethics and Professional Responsibility**

Evidence shows that technical competency contributes to students' ethical and professional development through emphasis on data integrity and design standards:

> *The importance of data integrity and honest reporting of results is a concept that is emphasised to the student. (Doc 1, NFQ 7).*
>
> *...introduces the standards required for professional CAD drawings and provides students with a framework to develop circuit and wiring diagrams using national and international graphical symbols and layouts (Doc 9, NFQ 7).*

These excerpts demonstrate the ethical implications of technical decisions, highlighting a foundational link between engineering ethics and technical accuracy.

- **PO6 Teamwork and Lifelong Learning**

Technical skills appear in the context of independent learning and information sourcing, supporting students’ progression toward self-reliance and adaptability:

> *They also need to display the ability to design and conduct experiments and simulations and interpret findings and data (Doc 2, NFQ 8).*
>
> *Development of lifelong learning skills is facilitated through the work students undertake in learning skills related to topics that may be unfamiliar to them such as artificial intelligence, microprocessor control, sensors, additive manufacturing and signal conditioning (Doc 13, NFQ 8).*

Although limited, these instances suggest an awareness of how emerging tools and self-directed learning support continuous technical development. In particular, this is one of the very few mentions of AI in the SARs, and its rarity is noted.

- **PO7 Communication**

Technical communication skills are developed alongside digital proficiency and collaborative tools:

> *Communication of design intent through drawings is developed in the CAD & Design stream with students developing skills and competencies in 2D and 3D parametric models (Doc 1, NFQ 7).*
>
> *…written presentation skills using technology as an aid and demonstrate the benefits of simulation for design optimisation and visualisation (Doc 1, NFQ 7).*

These extracts show how communication in engineering is deeply intertwined with technical language, digital drawing, and documentation.

- **PO8 Project Management**

Evidence of technical competency in this recently introduced PO focuses on the use of planning tools and software:

> *…apply planning & monitoring tools (Gannt charts, Network activity diagrams, resource charts) to simple projects (Doc 1, NFQ 7).*
>
> *The principles of project planning and contract management as it applies to engineering project are implemented with project management software like Network Arrow Diagrams, Activity on Arrow (AOA) and Microsoft Project (Doc 10, NFQ 8).*

Although limited in number, these references demonstrate the application of digital tools in managing engineering complexity.

Overall, the SARs show that although technical competency is not the primary focus of POs 5-8, it can operate as an enabling substrate, for instance, data integrity, standards compliance, CAD and simulation, experimentation and simulations, and project governance. However, this integration is uneven and often tool-led, with little evidence of explicit progression across NFQ levels or of emergent domains such as AI and data-driven decision-making.

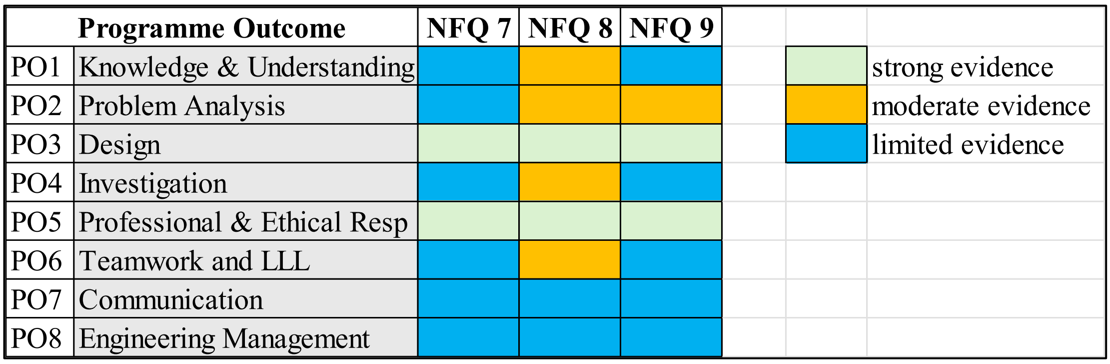
4.4.3 Sustainability

Given that sustainability awareness is foregrounded in both the Forward and Introduction to the EAIC (particularly with the inclusion of a new programme area PA7), it is not surprising that programmes presented evidence supporting sustainability activities. However, although the inclusion of PA7 highlights an objective of Engineers Ireland to focus on sustainability, there is no requirement for the HEI to explicitly address the PAs via the provision of evidence contained in the SARs, Therefore, all results and supporting extracts pertaining to sustainability are drawn from the POs.

Sustainability (a cornerstone of the Industry 5.0 framework) was evidenced across the POs of the SARs. As expected, the strongest and most consistent evidence emerged in PO5 and PO3, where environmental and ethical considerations are explicitly embedded in programme documentation as shown in Table 4-10. It appears in smaller pockets for PO1, PO2, PO4 and PO6 and is only weakly represented in PO7 and PO8, where evidence is limited at all levels.

This section first analyses PO5 and PO3, where sustainability is explicitly embedded and consistently evidenced across NFQ 7-9. It then presents the results from the remaining POs to identify partial or indirect alignment to sustainability.

Table 4-10 Sustainability matrix (POs x NFQ Level)



Programme Outcome		NFQ 7	NFQ 8	NFQ 9			
PO1	Knowledge & Understanding	🟦	🟧	🟦		🟩	strong evidence
PO2	Problem Analysis	🟦	🟧	🟧		🟧	moderate evidence
PO3	Design	🟩	🟩	🟩		🟦	limited evidence
PO4	Investigation	🟦	🟧	🟦			
PO5	Professional & Ethical Resp	🟩	🟩	🟩			
PO6	Teamwork and LLL	🟦	🟧	🟦			
PO7	Communication	🟦	🟦	🟦			
PO8	Engineering Management	🟦	🟦	🟦			

4.4.3.1 Sustainability in PO5 (Ethics and Professional Responsibility)

Analysis revealed the overarching finding from PO5 relates to the understanding of and commitment to professional and ethical responsibilities towards people and the environment in the practice of engineering. This highlights a deepening understanding of sustainability in the progression from NFQ level 7 to NFQ level 9.

- **NFQ Level 7 -** At this level, programmes introduce sustainability concepts in relation to environmental awareness, legal frameworks, and safety. These statements demonstrate how early exposure to sustainability principles is linked to professional conduct, regulation, and safe engineering processes:

  > *The learners are introduced to the need for safety in the practice of engineering through safety talks prior to the commencement of laboratory programmes, and the absolute need for appropriate safety and protective equipment while working the laboratories and workshops…safety and sustainability of the device (Doc 1, NFQ 7).*
  >
  > *Learners are introduced to the factors that combine to ensure this, including awareness of professional conduct and standards; relations with other engineers, other construction professionals, clients and employers; implications of their work on society and the environment (Doc 5, NFQ 7).*
  >
  > *Modules require an evaluation of health and safety, ethical considerations, and environmental protection regulations in engineering design (Doc 9, NFQ 7).*

- **NFQ Level 8:** At Level 8, the approach to sustainability becomes more embedded, with an emphasis on structured assessment tools and project-based application. These examples highlight the operationalisation of sustainability through formal tools and the integration of sustainability thinking into project workflows:

> *Many modules require an evaluation of health and safety, environmental impact and sustainability metrics as part of design justification (Doc 2, NFQ 8).*
>
> *Students conduct an EHS (Environmental, Health and Safety) assessment and consider sustainability criteria such as carbon footprint and lifecycle costs in their reports (Doc 4, NFQ 8).*
>
> *Environmental impact assessments and legislative context are incorporated into project planning to guide ethical and sustainable decision-making (Doc 10, NFQ 8).*

- **NFQ Level 9:** Postgraduate programmes focus on applying sustainability principles in complex, research-led contexts, reinforcing the societal role of engineers. These extracts reflect a shift from compliance to critical engagement, where students are expected to internalise sustainability principles and apply autonomously:

> *Research Methodology aims to enable students to consider the environmental and health implications of their project work, with an emphasis on lifecycle impact (Doc 3, NFQ 9).*
>
> *…consider implications of their work on society and the environment (Doc 7, NFQ 9).*
>
> *The programme emphasises the need for sustainable development, particularly the minimisation of environmental harm (Doc 14, NFQ 9).*

Overall, the approach to sustainability evidenced in PO5 reveals a structured and meaningful progression across all levels of education. From awareness and legal compliance at Level 7, through audit and evaluation tools at Level 8, to reflective and strategic integration at Level 9, the SARs demonstrate a strong alignment with the sustainability dimension of Engineering Education 5.0.

4.4.3.2 Sustainability in PO3 (Design)

Evidence of sustainability in PO3 reflects the importance of integrating environmental considerations into the engineering design process. While less frequently referenced than in PO5, the results reveal how sustainability principles are operationalised in design activities, particularly at higher NFQ levels.

- **NFQ Level 7 -** At this level, sustainability appears in design evaluations and system modelling tasks that prompt learners to reflect on functional and environmental impacts. These extracts demonstrate how technical evaluation is linked with performance optimisation and environmental criteria:

> *…assess their performance and critically evaluate these options taking into account cost, complexity and possible safety or environmental constraints (Doc 9, NFQ 7).*

> *Apply functional design to generate digital prototypes incorporating best engineering practices and identifying ethical/environmental impact considerations (Doc 12, NFQ 7).*
>
> *...develop a system model and use this model to develop suitable controllers, deploy them to assess their performance and critically evaluate these options taking into account cost, complexity and possible safety or environmental constraints...Safety and sustainability are key inputs to the design of these products and students are required to review safety and sustainability impacts as part of the process (Doc 15, NFQ 7).*

- **NFQ Level 8:** At Level 8, sustainability is addressed through design regulations, materials selection, and compliance with directives, suggesting a more structured engagement. These examples show sustainability being applied through the lens of regulation, standards, and system efficiency:

> *This includes understanding relevant directives and standards, application of concept generation tools, design embodiment, environmental considerations, redesign for function, manufacture, cost, recycling etc...Safety and sustainability are key inputs to the design of these products and students are required undertake detailed safety and sustainability audits as part of the product design process...Apply techniques in industrial ecology to reach an optimum environmental design to the full life cycle of a design..Assess and Employ Safety, Sustainability and Engineering Ethical Considerations in Product Development and Commercial Exploitation (Doc 2, NFQ 8).*
>
> *Students are assessed in the application of material balance methods for multiple units including recycle...Students acquire deep knowledge in designing of geometry and relevant process condition for a particular separation unit, while the purity of products, but also economical and sustainability aspects is considered (Doc 4, NFQ 8).*
>
> *...progress through design of elements to the design of complete structures and systems and the analysis of life cycle and environmental impact (Doc 6, NFQ 8).*

- **NFQ Level 9:** Postgraduate programmes demonstrate more flexible and critical design practices that integrate sustainability into systems-level thinking. These statements illustrate the role of sustainability not just as a constraint but as a core design principle shaping innovation and future-readiness:

> *Design methodologies need to be flexible to address open ended and sometime ill-defined problems. They also have to be rigorous enough to withstand evaluation of the final product with respect to compliance to standards and financial and environmental considerations (Doc 3, NFQ 9).*
>
> *Learners are introduced to experimental processes and data collection in laboratory work in the early stages of the programme, and progress through design of elements to the design of complete structures and systems and the analysis of life cycle and environmental impact (Doc 7, NFQ 9).*
>
> *...progress through design of elements to the design of complete systems and the analysis of life cycle and environmental impact (Doc 8, NFQ 9).*

Therefore, PO3 provides strong evidence of how sustainability principles are being embedded within the engineering design process. From initial exposure to modelling and simulation at Level 7, through regulatory compliance and environmental design criteria at Level 8, to system-level integration and strategic design at Level 9, the PO3 shows alignment with the sustainability feature of Engineering Education 5.0.

4.4.3.3 Sustainability in POs 1,2,4,6,7, and 8

While POs 1, 2, 4, 6, 7 and 8 do not consistently deal with sustainability, there is some evidence of its integration through secondary competencies, including material analysis, environmental regulation, teamwork, and impact communication. These results suggest a potential for broader curricular integration of sustainability beyond ethics and design, particularly as institutional understanding deepens.

- **PO1 Knowledge and Understanding:** A small number of SARs indicated that sustainability topics are being taught within science and engineering fundamentals. These examples illustrate early exposure to sustainability topics within core technical modules, often in the context of energy or thermodynamics

> *…introduced to wind, solar and hydro renewable energy systems and well as energy systems management…The maths module introduces differential and integral calculus and treats applications pertinent to sustainable energy (Doc 11, NFQ 8).*
>
> *Students are also introduced to aspects of environmental biotechnology (Doc 4, NFQ 8).*
>
> *Analyse, audit and apply thermodynamic principles and methods to both industrial & commercial enterprises, with a view to minimising operating costs, reducing GHG emissions and maximising renewable energy inputs (Doc 14, NFQ 9).*

- **PO2 Problem Analysis:** Some programmes demonstrate that problem-solving is being contextualised within sustainability considerations, particularly in material selection and energy modelling. These extracts show promising integration of sustainability into analytical skill development, though this was not uniformly reported across the SARs:

> *Energy analysis is applied to energy related problems…students use the SEAI's DEAP methodology and software to collect and input building data to determine a BER rating. That rating is then assessed against the current guidelines in TGD Part L with reference to MPEPC (Maximum Permitted Energy Performance Coefficient), MPCPC (Maximum Permitted Carbon Performance Coefficient) and renewable energy contribution (Doc 11, NFQ 8).*
>
> *…enables students to model energy consuming and converting systems…Analysis are made of different approaches to achieve maximum energy utilisation, with minimum emissions and environmental impact…Analyse complex thermodynamic cycles and renewable energy opportunities (Doc 14, NFQ 9).*
>
> *Select suitable materials for a particular design or application subject to appropriate design constraints whilst being mindful of Economic, Environmental and Societal issues (Doc 2, NFQ 8).*

Significant analysis is required from the start of the product design stage right through to final selection of materials and production process to ensure compliance with requisite standards and environmental metrics (Doc 3, NFQ 9).

They are trained to analyse and evaluate sustainability aspects for both types of separation processes and give relevant decisions in this regard (Doc 4, NFQ 8).

- **PO4 Investigation:** Limited but meaningful evidence was found of sustainability within investigative practices, particularly regarding regulation and field-based learning. These examples show sustainability in the curriculum through investigative assignments that link data collection to regulatory and environmental contexts:

…requires students to develop their skills while searching for relevant energy consumptions of various transportation alternatives…conduct literature reviews and investigate ways to reduce energy and environmental impact in products, processes, and organisations…students experiment with miniature solar and wind energy systems to demonstrate understanding of the operating characteristics of these sustainable energy systems. Students have to interpret results from a home energy audit and thermal comfort analysis and investigate the potential for decreasing energy usage and suggest sustainable energy generation measures for their home (Doc 11, NFQ 8).

The students research legislative requirements, they use CSO data and other statistics and they investigate sustainable materials…students conduct a semester long research project on the state of the Irish environment, on the treatment of waste building on their knowledge of the relevant EU directives, including the Industrial Emissions Directive, and considering Industrial Emissions licencing…each team must complete a HAZOP on an assigned unit (Doc 4, NFQ 8).

- **PO6 Teamwork and Lifelong Learning:** There is limited evidence of sustainability being framed as a team-based or lifelong learning competency, though some examples embed it into collaborative assignments. These cases illustrate how teamwork can serve as a platform for operationalising sustainability values, though it remains a secondary focus:

The students, as part of a team, must consider hazards and safety as part of their solution and manufacture (Doc 1, NFQ 7).

…students are asked to develop a sustainability strategy for an organisation taking one particular element (e.g. water use in building, active transport etc.) (Doc 11, NFQ 8).

…students work in teams to prepare a feasibility report on the sustainable production of a chemical product (Doc 4, NFQ 8).

- **PO7 Communication:** Few direct links between sustainability and communication were made. Where present, the focus was on group communication in sustainable design contexts. These activities highlight the potential for sustainability to enhance the authenticity and relevance of communication tasks:

The students, as part of a team, must consider and communicate the sustainability impacts of their proposals to peers and stakeholders (Doc 1, NFQ 7).

> *Requires students to work in groups to generate a sustainability brief and present environmental impact findings to industry panels (Doc 11, NFQ 8).*

- **PO8 Engineering Management:** Sustainability appeared occasionally in the context of project management and systems planning. Although limited, this example aligns well with the broader goals of Engineering Education 5.0, emphasising systems thinking and sustainability-conscious leadership:

> *This challenges learners to consider the various economic, environmental and social dimensions of project planning and resource management (Doc 2, NFQ 8).*

4.4.4 Ethics and social Impact

This feature reveals evidence related to the ethical implications of technology and the engineer's role in society. PO5 has been further enhanced from the 2014 edition of the EIAC (Engineers Ireland, 2014), so it is unsurprising that strong evidence of ethics was found across the documents to meet this mandatory PO. However, limited evidence of ethical considerations was found in the remaining POs. See Table 4-11 for an overview of the analysis, which shows a pattern indicating a concentration in PO5 and PO3 with an emphasis at NFQ 8, with weak vertical progression outside these outcomes and a tail-off at NFQ 9. This suggests ethics and social impact are present but unevenly scaffolded, moving from incidental mentions to explicit integration only in selected POs.

This section is presented in three parts. The first focuses on PO5 (Ethics and Professional Responsibility), second it examines how ethical considerations are embedded within the technical POs (PO1-PO4) and finally, explores ethical dimensions within the remaining non-technical POs (PO6-PO8), including teamwork, communication, and engineering management.

Table 4-11: Ethics and social impact matrix (POs x NFQ Level)

Programme Outcome		NFQ 7	NFQ 8	NFQ 9			
PO1	Knowledge & Understanding	🟧	🟧	🟦		🟩	strong evidence
PO2	Problem Analysis	🟦	🟧	🟦		🟧	moderate evidence
PO3	Design	🟧	🟩	🟩		🟦	limited evidence
PO4	Investigation	🟦	🟧	🟦			
PO5	Professional & Ethical Resp	🟩	🟩	🟩			
PO6	Teamwork and LLL	🟧	🟧	🟦			
PO7	Communication	🟧	🟧	🟦			
PO8	Engineering Management	🟧	🟧	🟦			

4.4.4.1 Ethics and social impact in PO5

As expected, PO5 contained the most extensive and structured evidence for ethics and social impact. The SARs show a progressive approach to developing students' ethical awareness and sense of professional responsibility, moving from regulatory compliance at Level 7 to values-based judgment and societal responsibility at Level 9.

- **NFQ Level 7:** At this level, programmes typically frame ethics through safety mandates, legal compliance, and early-stage reflection on the role of the engineer. They reflect a foundational approach to ethics, where responsibilities are framed through formal rules and professional conduct:

  Students are encouraged to envisage how their actions as engineers will impact on the wider world in both professional and societal contexts (Doc 1, NFQ 7).

  Students get first-hand experience with their responsibilities under environmental and safety legislation (Doc 15, NFQ 7).

  Compliance with appropriate safety mandates as defined in law is a core part of all lab-based work and project development (Doc 9, NFQ 7).

- **NFQ Level 8:** Level 8 programmes begin to link ethical frameworks and professional codes to real-world engineering dilemmas, supporting the idea that students are expected to demonstrate ethical judgment in applied contexts:

  From 1st Year, the underlying principles of responsible engineering are introduced including fairness, transparency, and integrity in decision-making (Doc 2, NFQ 8).

  Students observe the ethical standards relevant to data management, intellectual property, and communication with clients and the public (Doc 10, NFQ 8).

  The ethical obligations of engineers should be clearly understood and referenced within final year project reporting (Doc 11, NFQ 8).

- **NFQ Level 9:** At postgraduate level, ethical learning becomes critically reflective and societally oriented, reflecting the broader systems thinking and social accountability expected at postgraduate level:

  Graduates must be capable of realising the impact of engineering solutions in global, economic, environmental, and societal contexts (Doc 8, NFQ 9).

  Students need to be aware of their responsibilities in relation to environmental policy, data protection, and stakeholder engagement (Doc 3, NFQ 9).

  Must be capable of realising the importance of ethical leadership and its impact on organisational and societal systems (Doc 7, NFQ 9).

Overall, PO5 illustrates a strong and coherent trajectory in the development of ethics and social impact awareness across all NFQ levels. From safety and legal compliance in Level 7, to ethical frameworks and professional obligations in Level 8, and on to societal responsibility and reflective judgment at Level 9, this PO aligns closely with the ethics pillar of Engineering Education 5.0. The emphasis on student reflection, project-based accountability, and engagement with societal systems supports a transformative vision of engineering professionalism.

4.4.4.2 Ethics and social impact in PO1-PO4

While ethical and societal concerns are explicit in PO5, there is nonetheless some evidence across the technical POs, in particular PO3 (Design). These tend to emphasise compliance, risk awareness, and sustainability as ethical considerations, rather than moral reasoning per se.

- **PO1 - Knowledge and Understanding:** Ethical themes appear in the context of systems modelling, resource efficiency, and sustainability, particularly as students begin to consider the consequences of engineering decisions. Though not explicitly framed as ethics, these statements reflect an emerging recognition of the social and environmental consequences of technical knowledge:

  Using appropriate systems models coupled with energy audit techniques to improve understanding of the role engineers play in sustainability and resource impact (Doc 15, NFQ 7).

  Select suitable materials for a particular design based on cost, energy consumption, recyclability, and sustainability performance (Doc 2, NFQ 8).

- **PO2 - Problem Analysis:** Ethical responsibility in PO2 is often operationalised through scenario-based learning and engineering decision-making. These examples support the framing of ethical responsibility within analytical and evaluative processes:

  Apply ethical responsibility and document how engineering solutions are constrained by environmental, safety, and legal factors (Doc 2, NFQ 8).

  A focus on the practical application of engineering knowledge to problem-solving scenarios that require consideration of human and societal impact (Doc 10, NFQ 8).

- **PO3 - Design:** Ethics and social impact emerge through the lens of responsible innovation and professional responsibility in design processes. This suggests that PO3 is being used to embed ethical thinking in the practice of design, although references to social justice, inclusion or equity remain minimal:

  Provides students with a knowledge and understanding of health and safety legislation, standards and design practices (Doc 12, NFQ 7).

  Professional responsibilities towards society are explored during materials selection and energy use optimisation (Doc 4, NFQ 8).

  These experiments may include design of novel systems that prioritise environmental integrity and the wellbeing of end users (Doc 3, NFQ 9).

- **PO4 - Investigation:** PO4 features limited ethical integration, primarily through risk awareness and compliance practices. Although the focus is more procedural than reflective, these examples still reflect a foundational ethical awareness in investigative contexts:

> *Perform and report on laboratory experiments and ensure safety protocols are followed for all investigations (Doc 1, NFQ 7).*
>
> *Carry out a hazard analysis and write a safety case for experimental work (Doc 12, NFQ 7).*
>
> *Meet those specifications taking into account sustainability, safety and compliance with standards (Doc 9, NFQ 7).*

Across PO1 to PO4, ethical considerations are typically tied to professional safety, environmental responsibility, and legal compliance. While explicit ethical theory or debate is rare, these POs nonetheless show a baseline alignment with the ethics and social impact dimension of Engineering Education 5.0, especially through attention to regulation, societal needs, and responsible practice.

4.4.4.3 Ethics and social impact in PO6-PO8

Ethics and social responsibility are also present, although more sporadically, within the remaining non-technical POs. These findings suggest that ethical awareness is starting to permeate professional practices beyond traditional boundaries, including teamwork, communication, and engineering management.

- **PO6 - Teamwork and Lifelong Learning:** Evidence of ethics in teamwork contexts is limited, but one SAR suggests growing attention to group responsibility for safety and compliance. This implies that shared responsibility and ethical collaboration are being introduced, though more as a procedural concern than a value-driven competency:

  > *Must consider hazards and safety as part of the team-based decision-making process for experimental tasks (Doc 12, NFQ 7).*

- **PO7 - Communication:** PO7 contains a broader range of ethical and social themes, including transparency, accountability, and the ability to explain decisions to varied audiences. These examples reveal how communication is being framed not only as a skill but as an ethical obligation in professional and public settings:

  > *Students are taught to develop and document all design stages, emphasising traceability and ethical transparency (Doc 15, NFQ 7).*
  >
  > *The IGAESS (Integrating Graduate Attributes to Enhance Student Success) framework supports the development of inclusive and ethical communication (Doc 10, NFQ 8).*
  >
  > *Must possess the capability to articulate their decisions clearly and professionally to non-expert stakeholders (Doc 6, NFQ 8).*
  >
  > *They must communicate the decision process underpinning design or investigative choices, with reference to standards, constraints and impacts (Doc 4, NFQ 8).*

- **PO8 - Engineering Management:** Evidence in PO8 links ethics to organisational awareness and systems-level decision-making. These results suggest a growing recognition of how ethics extends to leadership, accountability, and the governance of engineering systems:

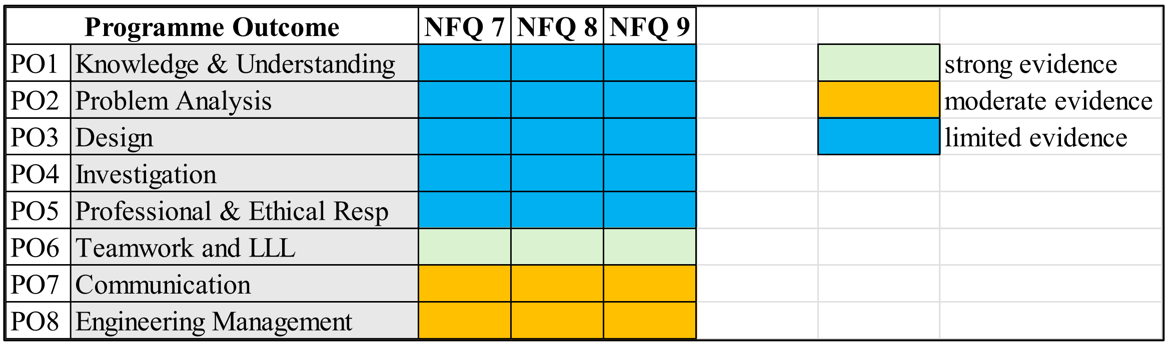
> *Details the management tools required by the learner to support safety, social responsibility and compliance (Doc 9, NFQ 7).*
>
> *Apply the fundamentals of maintenance management with attention to safe and ethical systems planning (Doc 13, NFQ 8).*
>
> *Graduates need to be aware of the organisational culture and ethical obligations involved in managing engineering processes (Doc 4, NFQ 8).*
>
> *Need to be aware of the organisational structures that support ethical decision-making and systems accountability (Doc 11, NFQ 8).*

In summary, PO6-PO8 demonstrate emerging evidence of ethics and social impact being embedded into teamwork, communication, and management. While references remain limited, there is a clear trajectory toward understanding professional roles and responsibilities in broader organisational and social contexts.

4.4.5 Collaboration

As expected, and as can be seen in Table 4-12 PO6 (Teamwork and Lifelong Learning) demonstrates the strongest and most consistent evidence of collaboration, with structured activities across all educational levels. In contrast, PO7 and PO8 show more limited but meaningful references to collaboration, particularly through project-based teamwork and stakeholder coordination. No substantial evidence of collaboration was identified in the remaining POs.

Table 4-12: Collaboration matrix (POs x NFQ Level)



Programme Outcome		NFQ 7	NFQ 8	NFQ 9
PO1	Knowledge & Understanding	🟦	🟦	🟦
PO2	Problem Analysis	🟦	🟦	🟦
PO3	Design	🟦	🟦	🟦
PO4	Investigation	🟦	🟦	🟦
PO5	Professional & Ethical Resp	🟦	🟦	🟦
PO6	Teamwork and LLL	🟩	🟩	🟩
PO7	Communication	🟧	🟧	🟧
PO8	Engineering Management	🟧	🟧	🟧

🟩	strong evidence
🟧	moderate evidence
🟦	limited evidence

4.4.5.1 Collaboration in PO6

PO6 provided the strongest evidence for collaboration within the SARs. Across all NFQ levels, teamwork was consistently emphasised as a structured component of the engineering curriculum.

Evidence shows a developmental progression from task-based collaboration in lower levels to complex, interdisciplinary teamwork in postgraduate programmes.

- **NFQ Level 7:** At this level, collaboration is primarily introduced through laboratory activities, structured group tasks, and the development of basic teamwork competencies. These statements emphasise foundational skills in collaboration, such as shared responsibility, communication, and participation:

  Learners are introduced to teamwork in laboratory and design environments to develop communication and interpersonal skills (Doc 1, NFQ 7).

  Graduates must have the ability to work as individuals and as members of a team, contributing to discussions and collective decision-making (Doc 5, NFQ 7).

  Students work in teams to measure and record process variables, sharing the responsibility for experimental design and outcomes (Doc 9, NFQ 7).

- **NFQ Level 8:** By Level 8, teamwork is increasingly linked to engineering design, applied projects, and assessment. Learners engage in more open-ended and creative collaborative tasks. These examples show collaboration extending beyond logistical cooperation into co-creation, reflection, and interdisciplinary practice:

  Students work in groups on a team project to design and prototype a device that meets a defined need (Doc 2, NFQ 8).

  Learners are introduced to teamwork in laboratory and project environments and are encouraged to reflect on their team contributions in assessments (Doc 4, NFQ 8).

  Students take part in interdisciplinary design activities requiring effective collaboration across subject areas (Doc 6, NFQ 8).

- **NFQ Level 9:** Postgraduate programmes expect students to collaborate in diverse, self-directed, and professional contexts. Collaboration becomes a strategic and ethical competency. Here, collaboration is framed as both a technical and ethical expectation, closely aligned with real-world team dynamics and stakeholder diversity:

  In the 4th year modules of the masters programme, students are expected to work in teams on industry-based projects requiring collaborative planning and execution (Doc 3, NFQ 9).

  Must have the ability to work as Engineers alongside peers and non-engineers, especially in multidisciplinary project settings (Doc 7, NFQ 9).

  In teams and with others in diverse and multidisciplinary settings, students are encouraged to contribute effectively and ethically to team objectives (Doc 8, NFQ 9).

In conclusion, PO6 provides strong, consistent evidence of how collaboration is integrated and developed across the curriculum. The trajectory, from basic group work to interdisciplinary, industry-facing collaboration, aligns well with the collaborative ethos of Engineering Education

5.0. There is also evidence of reflective practice and ethical teamwork at higher levels, reinforcing the view of collaboration as a professional competency.

4.4.5.2 Collaboration in PO7 and PO8

Although PO6 explicitly addresses teamwork, results also show that collaboration is integrated into related professional competencies, particularly in PO7(Communication) and PO8 (Engineering Management). These POs frame collaboration not only as interpersonal coordination but also as a structured practice involving planning, documentation, and stakeholder engagement.

- **PO7 Communication:** Team-based communication practices are well-represented in PO7, particularly in group reports, collaborative writing, and peer coordination. These representative examples illustrate how communication is being contextualised within collaborative authorship and structured documentation, strengthening students' ability to coordinate, represent, and communicate shared knowledge:

  They create a communication strategy detailing the flow of information, timelines and responsibilities for all team members (Doc 1, NFQ 7).

  Students must also write a technical report on behalf of the group, incorporating feedback from peer review (Doc 4, NFQ 8).

  Students work in teams to analyse peer-reviewed articles and produce a collective report on their findings (Doc 3, NFQ 9).

- **PO8 Engineering Management:** Collaboration in PO8 is framed as a management competency, with emphasis on planning, leadership, and team-based project execution. Here, collaboration becomes a matter of governance, conflict management, strategic planning, and responsiveness, as well as working together. This aligns well with the broader leadership and systems-awareness ambitions of Engineering Education 5.0 as illustrated in the extracts below:

  Students detail how they are going to manage the team dynamic and address potential conflicts before starting the assignment (Doc 12, NFQ 7).

  Each team creates and signs up to a team charter and governance plan to support collaborative decision-making (Doc 4, NFQ 8).

  Projects can include third-party stakeholders and learners must demonstrate an ability to plan and adapt as a team in response to stakeholder needs (Doc 3, NFQ 9).

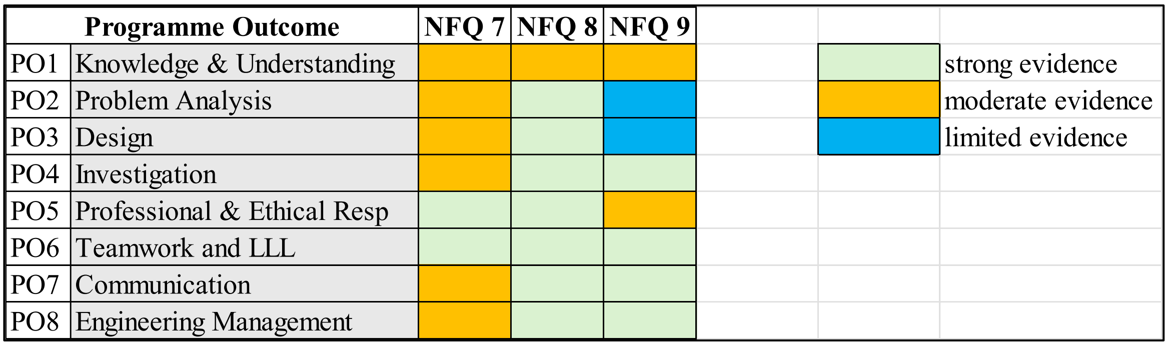
In summary, while PO6 remains the primary domain for teamwork development, POs 7 and 8 provide results that collaboration is being reinforced through communication strategy and team-based project management. These findings point to an increasingly integrated view of collaboration, both as an interpersonal skill and as a critical part of professional engineering practice.

4.4.6 Educational approach

In the Engineering Education 5.0 model, the educational approach feature emphasises lifelong learning, self-directed learning, adaptability, and personalised education. The results from the POs demonstrate comprehensive evidence across all programmes, revealing students' preparation for lifelong learning, such as through CPD. As illustrated in Table 4-13: Educational approach matrix (POs x NFQ Level), strong evidence was found in PO6, which was somewhat unexpected as PO6 is dedicated to lifelong learning.

It is also noted that very limited evidence relating to how personalised learning and flexibility in education are incorporated, was found across the POs. This was not surprising as Engineers Ireland's EIAC does not have a remit to address delivery models or pedagogical approaches as part of the accreditation process.

Table 4-13: Educational approach matrix (POs x NFQ Level)



Programme Outcome		NFQ 7	NFQ 8	NFQ 9
PO1	Knowledge & Understanding	🟧	🟧	🟧
PO2	Problem Analysis	🟧	🟩	🟦
PO3	Design	🟧	🟩	🟦
PO4	Investigation	🟧	🟩	🟩
PO5	Professional & Ethical Resp	🟩	🟩	🟧
PO6	Teamwork and LLL	🟩	🟩	🟩
PO7	Communication	🟧	🟩	🟩
PO8	Engineering Management	🟧	🟩	🟩

🟩	strong evidence
🟧	moderate evidence
🟦	limited evidence

4.4.6.1 Educational approaches in PO6

PO6, the clearest examples of educational strategies intended to support the development of lifelong learning and teamwork. Across all NFQ levels, deliberate approaches to curriculum design, learner reflection, and active engagement are evident. The pedagogical shift from structured learning to self-directed development is clearly observable across levels.

- **NFQ Level 7:** At Level 7, the educational approach focuses on the acquisition of foundational learning skills and the ability to reflect on professional development. These examples show how lifelong learning is introduced as a formal educational objective, supported by reflective practice and adaptable curriculum structures:

  > *Graduates must be capable of recognising the requirements of continuing education and have developed skills to support lifelong learning (Doc 1, NFQ 7).*
  >
  > *dynamic environment in which they will work, students must be capable of acquiring new skills and being adaptable to emerging demands (Doc 15, NFQ 7).*

- **NFQ Level 8:** By Level 8, programmes increasingly support independent learning, goal setting, and the ability to manage one's own development. These statements illustrate a progression toward learner autonomy and self-regulation, consistent with the educational philosophy underpinning Engineering Education 5.0:

> *Students undertake learning skills related to self-management, independent research, and personal goal setting (Doc 13, NFQ 8).*
>
> *It requires them to plan, set goals and actively reflect on their progress toward achieving learning outcomes (Doc 2, NFQ 8).*
>
> *Requires the student to engage in self-directed project work supported by mentoring and interim reporting structures (Doc 10, NFQ 8).*

- **NFQ Level 9:** At Level 9, educational approaches are focused on individualised learning, critical reflection, and long-term professional development. These examples support the expectation that students at this level can navigate their own learning processes within complex and ill-defined professional contexts:

> *Preparation for lifelong learning is developed through emphasis on reflective writing, formative feedback and critical thinking about learning strategies (Doc 3, NFQ 9).*
>
> *The nature of individual assignment and assessment requires the learner to plan, manage and evaluate their learning across complex, open-ended scenarios (Doc 7, NFQ 9).*

Thus, PO6 provides clear evidence of an integrated educational approach to developing lifelong learning. The transition from tutor-supported reflection at Level 7 to autonomous, critically reflective practice at Level 9 is supported by modular scaffolding, self-assessment, and goal-setting practices. This PO exemplifies the pedagogical dimension of Engineering Education 5.0 and highlights the system's commitment to graduate preparedness for continuous personal and professional development.

4.4.6.2 Educational approaches in PO1-PO4

While PO6 is the primary locus for evidence of educational strategy and learning design, the technical POs (PO1-PO4) also reveal important pedagogical patterns. These include progressive curriculum design, independent research, reflective learning, and structured assessment, all aligned with the ethos of Engineering Education 5.0.

- **PO1 Knowledge and Understanding:** This example highlights a recursive learning design aimed at deeper knowledge retention, a hallmark of learner-centred education:

> *The module builds on previous modules, taking a spiral approach to learning that reinforces earlier concepts in a more applied setting (Doc 3, NFQ 9).*

- **PO2 Problem Analysis:** These entries support the idea that analysis skills are taught progressively, with embedded reflection and feedback loops supporting deeper learning:

> *Systematically review and adapt the design during the project development phase in light of learner reflections and peer feedback (Doc 13, NFQ 8).*
>
> *The progression of core subjects to discipline-specific modules is scaffolded to build the students' problem-solving capacity over time (Doc 2, NFQ 8).*

- **PO3 Design:** The educational approach in PO3 balances theoretical inquiry with hands-on application, supported by structured guidance and scaffolding:

> *Project Research & Design allows students to apply theoretical concepts in practice, with extensive support through tutorials and formative feedback (Doc 1, NFQ 7).*
>
> *Produce a comprehensive literature survey of the design space to support student understanding of innovation and constraints (Doc 12, NFQ 8).*
>
> *Students present a safety case study covering relevant legislation, which is used as the basis for a team design activity (Doc 4, NFQ 8).*

- **PO4 Investigation:** These extracts reflect an inquiry-led learning model with structured support for independence and reflective decision-making:

> *They must systematically review and adapt the investigative methodology throughout the project in line with emerging evidence (Doc 10, NFQ 8).*
>
> *Projects are conducted on an individual basis and require students to plan and evaluate their work in consultation with their mentor (Doc 14, NFQ 9).*

4.4.6.3 Educational approaches in PO5, -PO7-8

In addition to PO6 and the technical POs, evidence from PO5, PO7, and PO8 demonstrates some pedagogical features. These include scaffolded learning strategies, active engagement, and professional simulation practices.

- **PO5 Ethics and Professional Responsibility:** This reflects a mix of procedural compliance and emerging opportunities for reflective and dialogic engagement:

> *The most significant indication of achieving the learning outcome is the student's documented reflection on their responsibilities as a professional engineer (Doc 12, NFQ 7).*
>
> *Students are provided with a copy of the laboratory safety manual and must sign a declaration of understanding before commencing experiments (Doc 9, NFQ 7).*
>
> *Learning is a two-way process… Students must also critique ethical scenarios and present their own arguments during class discussions (Doc 4, NFQ 8).*
>
> *Typically, students undergo specific training in legislation, standards and safety documentation before conducting field work (Doc 2, NFQ 8).*

- **PO7 Communication:** These examples show an evolution from structured templates to diverse, independent communication formats, reflecting a pedagogical strategy for developing technical literacy and professional expression:

> *Report writing for labs will generally start with structured templates and evolve toward more independent and self-directed formats by Year 3 (Doc 9, NFQ 7).*
>
> *Communicating within the group and disseminating outcomes to external audiences is supported through written and oral assessment modes (Doc 2, NFQ 8).*
>
> *Presentations are given in person orally and supported by a visual technical report to be evaluated by the academic team (Doc 3, NFQ 9).*

- **PO8 Engineering Management:** The extracts here emphasise experiential learning, with a clear pedagogical focus on autonomy, planning, and adaptability:

> *Time management is critical in ensuring these projects are delivered on time and students are taught to use scheduling tools from Year 1 (Doc 1, NFQ 7).*
>
> *Risk management and maintenance management also feature strongly in the curriculum as active learning themes (Doc 2, NFQ 8).*
>
> *Students must log their time (billable hours) and reflect on the balance between administrative and engineering work (Doc 4, NFQ 8).*
>
> *Plans must be actioned and adjusted to the evolving needs of the team and project context, requiring adaptive learning and feedback (Doc 3, NFQ 9).*

Therefore, while PO6 remains the most explicit domain of pedagogical development, both technical (PO1-PO4) and non-technical (PO5, PO7-PO8) programme outcomes demonstrate consistent integration of learner-centred approaches across the engineering curriculum. These include scaffolded progression, reflective practice, and active learning strategies aligned with the Engineering Education 5.0 vision.

4.4.7 Global and cultural perspectives

As summarised in Table 4-14, analysis of the POs indicates that explicit engagement with global and intercultural perspectives is sparse, fragmented, and uneven across the POs. While Engineering Education 5.0 underscores the need for graduates to operate with global awareness and intercultural competence, most references found are indirect. That said, there is some evidence of engagement with international standards, global challenges, and diverse stakeholder perspectives, most notably within the non-technical POs (PO5-PO8) and to a lesser extent within the technical POs (PO1-PO4).

Table 4-14: Global and cultural perspectives matrix (POs x NFQ Level)

Programme Outcome		NFQ 7	NFQ 8	NFQ 9			
PO1	Knowledge & Understanding	🟦	🟨	🟦		🟩	strong evidence
PO2	Problem Analysis	🟦	🟨	🟦		🟨	moderate evidence
PO3	Design	🟨	🟨	🟦		🟦	limited evidence
PO4	Investigation	🟦	🟨	🟦			
PO5	Professional & Ethical Resp	🟦	🟩	🟦			
PO6	Teamwork and LLL	🟦	🟨	🟦			
PO7	Communication	🟦	🟨	🟦			
PO8	Engineering Management	🟦	🟨	🟦			

4.4.7.1 PO5 Ethics and Professional Responsibility

Within PO5, the extracts demonstrate the requirement for students to work in multi-disciplinary teams, which can be foundational to intercultural competence. Likewise, the emphasis on safety, sustainability, engineering management, and adherence to international standards situates students within globally recognised regulatory and professional frameworks, reinforcing ethical responsibility at a transnational level. However, while these elements signal awareness of global practice, they stop short of engaging students with the ethical complexities of cultural diversity, global inequities, or the societal consequences of engineering across different contexts. As such, the extracts demonstrate partial but limited alignment with the global and intercultural aspirations of Engineering Education 5.0:

> *Students work in multi-disciplinary teams* (Doc 4, NFQ 8).
>
> *Implementation of safety, sustainability, engineering management and international standards is required throughout the project (Doc 13, NFQ 8).*

4.4.7.2 PO6 Teamwork and lifelong learning

In PO6, the extracts emphasise multidisciplinary and, in some cases, multicultural teams as central to student learning, whether through integrated product design modules, placements, or action-learning programmes. These contexts expose students to diverse perspectives, requiring adaptability, interpersonal competence, and initiative in real-world settings. Such experiences align with Engineering Education 5.0's focus on preparing graduates for collaborative, dynamic, and globally connected workplaces:

> *The multidisciplinary Integrated Product Design module (Doc 3, NFQ 9).*
>
> *As part of the ten-week placement students work in multicultural/ multidisciplinary teams (Doc 9, NFQ 7).*
>
> *The developed action-learning programmes brings multidisciplinary teams together from various backgrounds and specialities (Doc 13, NFQ 8).*

> *While on placement students should demonstrate initiative and interpersonal skills and contribute effectively to a workplace team and this further develops their engineering competence as part of their placement (Doc 16, NFQ 8).*

However, while the extracts demonstrate functional preparation for teamwork and continuous professional growth, they offer limited evidence of deeper engagement with intercultural dynamics or the broader societal dimensions of lifelong learning:

4.4.7.3 PO7 Communication and PO8 Engineering Management

PO7 reflects global perspectives through the requirement to produce CAD drawings and wiring diagrams using internationally recognised standards. This situates communication within global professional conventions, ensuring technical outputs are transferable across borders. However, as can be seen in the extract below, the focus is functional, with little evidence of intercultural adaptation or engagement with diverse communicative contexts:

> *Introduces the standards required for the communication of design ideas into implementable systems CAD drawings and ensures that students produce professional circuit and wiring diagrams using national and international layouts (Doc 10, NFQ 8).*

PO8 engages global and cultural perspectives through analysis of enterprise culture, governance, and legal frameworks, alongside structured reporting practices. These extracts highlight awareness of organisational diversity and transnational management environments. Yet, the emphasis remains on formal structures rather than the intercultural or ethical complexities of managing across cultural boundaries:

> *Critically analyse the enterprise, its culture and its organisation (Doc 2, NFQ 8).*
>
> *A strong understanding of organizational structures, commercial governance, legal principles and contractual agreement. (Doc 6, NFQ 8).*
>
> *They produce quarterly reports that summarise progress along with any constraints or issues that might affect progress and discuss mitigation plans with their supervisors for these (Doc 11, NFQ 8).*

4.4.7.4 Technical POs (PO1-PO4)

Much less attention is accorded to global and cultural perspectives across PO1-PO4. There are very few references, and they tend to focus on technical issues such as engagement with international variations in technical standards and do not demonstrate any deeper engagement with cultural or global societal concerns.

The following example from PO1 (Knowledge and Understanding) suggests some engagement with international variation in systems or standards. Although the phrasing is general and the depth of treatment is unclear, it reflects an intention to raise students' awareness of how engineering knowledge and application can vary across cultural or jurisdictional boundaries.

> *Discuss the principles of compatibility in different cultural and regulatory contexts (Doc 2, NFQ 8).*

An extract from PO2 (Problem Analysis) reflects an intention to raise students' awareness of how engineering knowledge and application can vary across cultural or jurisdictional boundaries.

> *Integrate major international device standards (FDA, ASTM) and hazard analysis techniques into the mechanical design, operation and safety of components and machine (Doc 2, NFQ 8).*

Similarly, extracts from PO3 (Design) highlight that the emphasis is solely on developing student knowledge and ability to use standards from a global perspective:

> *Integrate major international standards (DIN, ISO, BS, Machinery Directive (Doc 1, NFQ 7).*
>
> *Students also learn about/research the relevant legislation and international standards in this field (Doc 11, NFQ 8).*

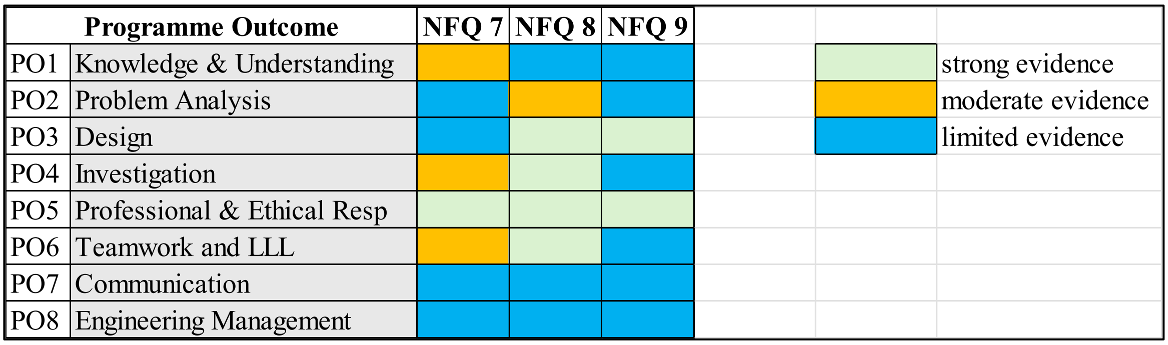
Finally, analysis of PO4 (Investigation)suggests limited exposure to the global research and innovation landscape by demonstrating an introductory understanding of global intellectual property systems, which are critical for engineers operating in international contexts. Nevertheless, this extract stops short of addressing cultural variation in research ethics, global data regulation, or diverse knowledge systems.

> *Students are introduced to the patent literature and the international IP landscape as part of the research module (Doc 4, NFQ 8).*

4.4.8 Holistic and human-centric

The results reveal uneven attention across the POs where holistic and human-centricity are concerned. As illustrated in Table 4-15, strong evidence was found across all NQF levels in PO5 (Ethics and Professional Responsibility), followed by PO3 (Design), PO4 (Investigation), and PO6 (Teamwork), where evidence suggests growing attention to empathy, equity, and social impact. In other POs, these values are either nascent or absent, indicating room to broaden the human-oriented framing of engineering education across the curriculum.

Table 4-15: Holistic and human-centric (POs x NFQ Level)



Programme Outcome		NFQ 7	NFQ 8	NFQ 9
PO1	Knowledge & Understanding	🟧	🟦	🟦
PO2	Problem Analysis	🟦	🟧	🟦
PO3	Design	🟦	🟩	🟩
PO4	Investigation	🟧	🟩	🟦
PO5	Professional & Ethical Resp	🟩	🟩	🟩
PO6	Teamwork and LLL	🟧	🟩	🟦
PO7	Communication	🟦	🟦	🟦
PO8	Engineering Management	🟦	🟦	🟦

🟩	strong evidence
🟧	moderate evidence
🟦	limited evidence

4.4.8.1 Holistic & human-centric in PO5 Ethics and Professional Responsibility

PO5 offers the richest evidence of holistic and human-centricity across all programme outcomes, with a clear trajectory from introductory principles of fairness and accountability at Level 7, to empowerment at Level 8, and an integrated ethical worldview at Level 9. The focus on ethical awareness, equal treatment, and social consideration reflects a deepening engagement with values-led engineering education, while the emphasis on diversity, wellbeing, and inclusive design aligns closely with the core priorities of Engineering Education 5.0.

As shown in the following extracts, at Level 7 students are introduced to fairness and diversity principles within both classroom and laboratory contexts, where the developmental and orienting tone supports an early-stage awareness of human-centred responsibility. At level 8, they also demonstrate more explicit and applied engagement with ethical and human-centred principles, where students begin to reflect on these values in relation to project work, communication, and stakeholder involvement. While at level 9, students are expected to engage with engineering as a fundamentally human-centred discipline. The shift from procedural to value-driven engagement is clearest at this level.

- **NFQ Level 7**

  The awareness of the need to ensure equal treatment and consideration of diverse perspectives is introduced early in the programme (Doc 9, NFQ 7).

  From 1st Year, the underlying principles of respect and accountability are embedded in student codes of conduct (Doc 12, NFQ 7).

  Equal treatment and consideration of diverse user needs is embedded into the lab safety and ethics training module (Doc 15, NFQ 7).

- **NFQ Level 8**

  The underlying principles of respect for the person, equal access and social responsibility underpin the ethics teaching in Year 3 (Doc 16, NFQ 8).

  The awareness of the need to ensure equal treatment and consideration of user experience is discussed in workshops and assessed via reflective report (Doc 10, NFQ 8).

  Identifies the engagement and empowerment of people as a core aspect of project planning and stakeholder consultation (Doc 2, NFQ 8).

- **NFQ Level 9**

  Enable students to develop an understanding of engineering as a human-centred profession that must prioritise wellbeing, equity and long-term societal impact (Doc 3, NFQ 9).

4.4.8.2 Holistic and Human-centric in PO3, PO4 and PO6

Evidence of holistic and human-centricity in PO3 (Design) is found in the explicit reference to human-centered design and the requirement to align with legislative and industry standards, while project costing and functionality tasks highlight the integration of technical, economic, and social considerations.

Results from PO4 (Investigation) suggest that investigation can include reflection on the human and social dimensions of engineering research and is not limited to technical accuracy. The progression from technical review to social awareness and equity indicates the embedding of human-centric criteria into inquiry-based learning. Moreover, as demonstrated in the extracts from PO6 (Teamwork and Lifelong learning), teamwork is positioned as a site of inclusive learning and active citizenship. These examples reflect a strong alignment with Engineering Education 5.0 principles of community engagement, shared leadership, and holistic learning experiences

- **PO3 Design**

> *Human-centered design is a core component of the work and legislative and industry standards must be considered (Doc 4, NFQ 8).*
>
> *The student is required to develop a full project costing and to source and cost the required materials and must demonstrate the project functionality and outline the project development process in the final module assessment (Doc 16, NFQ 8).*

- **PO4 Investigation**

> *Produce a comprehensive literature survey of the design space to support student understanding of innovation and constraints (Doc 12, NFQ 7).*
>
> *Students must defend the validity of the sources chosen and reflect on potential societal impacts of engineering interventions (Doc 10, NFQ 8).*
>
> *The students conduct searches of peer-reviewed sources that prioritise health and social equity alongside technical feasibility (Doc 4, NFQ 8).*

- **PO6 Teamwork and Lifelong Learning**

> *The skills and competencies are acquired in a setting where different perspectives are encouraged, and equal participation is promoted (Doc 15, NFQ 7).*
>
> *The students, as part of a team, use best practice in project management to ensure all voices are heard (Doc 12, NFQ 7).*
>
> *Fosters knowledge, understanding and active participation in diverse teams and community-focused projects (Doc 4, NFQ 8).*

4.4.8.3 Holistic and human-centric in POs 1,2,7, and 8

Evidence for holistic and human-centricity in the remaining programme outcomes is limited but not entirely absent. Where it does appear, it often takes implicit or procedural forms centred on empathy, contextual awareness, and social responsibility. As shown in the following extracts, in PO1 (Knowledge and Understanding), students link human activity with carbon emissions and environmental change, reflecting awareness of engineering's societal and ecological impact. PO2 (Problem Analysis) highlights collaborative problem-solving across disciplines, suggesting openness to diverse perspectives in generating solutions. PO7 (Communication) fosters interpersonal awareness through peer communication in group assignments and labs, supporting the development of relational competence. Finally, PO8 (Engineering Management) engages students in socio-technical problem-solving within structured management frameworks, where teamwork and consideration of device requirements hint at sensitivity to organisational and social contexts. Collectively, these examples indicate that while human-centric elements are present, they remain partial and often embedded indirectly within technical or procedural learning activities.

- **PO1 Knowledge and Understanding**

  Students assess linkages between human activities, carbon emissions, and changes to the earth's energy balance (Doc 11, NFQ 8).

- **PO2 Problem Analysis**

  Combining ideas and contributions from different people and disciplines to arrive at appropriate engineering, technical or scientific solutions (Doc 4, NFQ 8).

- **PO7 Communication**

  Peer communication is developed through group interaction within group labs and group assignments throughout the programme (Doc 15, NFQ 7).

- **PO8 Engineering Management**

  The learners are constrained by adopting a management structure which is applied to the clinical area by aligning various device requirements, this is achieved by forming the learners in groups to tease out the solution to this socio-technical problem (Doc 2, NFQ 8).

4.4.9 How is Engineering Education 5.0 operationalised in the POs of SARs?

In order to address sub research question three, the documentary analysis of the POs in the SARs reveals that Engineering Education 5.0 is represented particularly well in technical competency, sustainability, ethics, and collaboration. These features map closely to Industry 5.0's emphasis on technological advancement that is also socially and ethically grounded.

Technical skills are robustly developed from foundational to advanced levels (NFQ 7-9), with a growing emphasis on data science and emerging technologies, although references to AI remain limited. Sustainability is consistently integrated, especially through design and ethical responsibility, though often represented through tools rather than deeply embedded principles. Ethics and social responsibility are central, particularly in PO5, and supported across technical and non-technical POs. Collaboration is comprehensively addressed, especially in teamwork, communication, and management-related outcomes.

However, the features of the educational approach, global and cultural perspectives, and holistic, human-centric engineering are less consistently represented. While lifelong learning and adaptability are evident, personalised and inclusive learning approaches are not strongly emphasised. Global awareness appears sporadically, and the integration of cultural competence is minimal. Human-centricity is most visible in PO5 through a focus on EDI and social inclusion, with some support from teamwork and investigative practices. Overall, as discussed in Chapter Five, while the SARs reflect a solid foundation aligned with Engineering Education 5.0, there are noticeable gaps in more fully embedding global, inclusive, and human-centred dimensions of the framework. Therefore, the full operationalisation of Industry 5.0 remains emergent, particularly in its more inclusive, global, and human-centred dimensions.

4.5 Conclusion

This chapter presented key results from interviewee insights, the updated EIAC criteria, and the POs from the SARs, highlighting uneven alignment with the features of Engineering Education 5.0. While progress is evident, areas for further development remain. Chapter Five builds on this evidence by integrating the three datasets through Ball's (1993) policy cycle framework, tracing how Industry 5.0 priorities are negotiated in the context of influence, codified in the context of text production, and translated, selectively and with tensions, within the context of practice. In doing so, it shows how accreditation both enables and constrains how far engineering programmes can be oriented toward Industry 5.0 in practice.

Chapter 5: Findings and Discussion

5.1 Introduction

This study critically examines how **Engineering Education** 5.0 is constructed through accreditation practices in engineering programmes within an Irish higher education institution, as viewed through the analytical lens of the model of Engineering Education 5.0. Building on the three sub-research questions, Chapter 4 presented the empirical results of the study; this chapter integrates those findings to address the overarching research question.

> **Through the lens of Engineering Education 5.0, how does accreditation in engineering programmes at a Higher Education Institution in Ireland prepare students for Industry 5.0?**

In addition to analysing the insights gained from the overall findings of this study, these results are examined in the context of the most recent body of academic studies and publications in the field. The model of Engineering Education 5.0 presented in Chapter Two, which served as the analytical tool for exploring the emergence of Industry 5.0 within engineering education in this study, is also re-evaluated in light of the findings from this study. The chapter begins by presenting a brief account of how the most recent literature was selected for this discussion. Then, similar to previous chapters, each of the seven features of Engineering Education 5.0 is discussed individually before the overarching research question is considered. This is followed by a reflection on the Engineering Education 5.0 model.

5.2 Selection of relevant recent publications

As part of this discussion section, recent relevant publications were sourced and incorporated into both the findings and a reflection on the Engineering Education 5.0, which emerged in Chapter Two. Using keywords “Industry 5.0” and “engineering education” or “Engineering Education 5.0,” and following the same steps as in Chapter Two, databases were searched and filters yielding a set of papers for analysis; a selection is shown in Table 5-1.

Table 5-1: Relevant papers published in 2024 and 2025

Date	Author	Title
2025	Arregi et al.	Instructional Design as a Key Factor for Industry 5.0 Engineering Education
2024	Balart and Shryock	A Framework for Integrating AI into Engineering Education, Empowering Human-Centered Approach for Industry 5.0
2025	Caratozzolo et al.	Continuing engineering education for a sustainable future
2024	Caratozzolo et al.	The New Engineering Education to Face Industry 5.0 Challenges
2025	Chakraborty and Galatro	Artificial Intelligence (AI) Equality in Engineering Education: Strategies to Unite the AI Gap between the Global North & South
2024	Ciolacu et al.	Education 5.0: Transforming Engineering Education in the Age of Generative AI
2024	Ciolacu et al.	Does Industry 5.0 Need an Engineering Education 5.0? Exploring Potentials and Challenges in the Age of Generative AI
2024	Doss, et al.	Education for Industry 5.0 and ESD: Co-Creation of Engineering Design Challenges with Industry
2025	Firescu	Increasing Collaboration Between Humans and Technology Within Organizations: The Need for Ergonomics and Soft Skills in Engineering Education 5.0
2025	Galatro and Chakraborty	Strategies to Map Education 5.0 and Industry 5.0 in the Context of a Modernized Undergraduate Program in Chemical Engineering
2025	Golser et al.	Integrating Stakeholder Engagement: Refining Engineering Education for the Mobility Value Chain in Industry 5.0
2025	Koch	Preparing Students for Industry 5.0: Evaluating the Industrial Engineering and Management Education
2024	Kovari	Transforming Engineering Pedagogy for the Fifth Industrial Revolution
2024	Lagorio and Cimini	Towards 5.0 skills acquisition for students in industrial engineering: the role of learning factories
2025	Luger et al.	Investigating the Influence of the Transition from Industry 4.0 to 5.0 on the Education and Career Development of Industrial Engineers and Managers
2024	Luna et al.	Challenges for Education in the New Era: Education and Training in Industry 5.0 Roles
2024	Pacher et al.	Engineering education 5.0: a systematic literature review on competence-based education in the industrial engineering and management discipline
2024	Padovano and Cardamone	Towards human-AI collaboration in the competency-based curriculum development process: The case of industrial engineering and management education
2024	Supriya et al	Industry 5.0 in smart education: Concepts, applications, challenges, opportunities, and future directions
2024	Vieira	Engineering Education in Industry 5.0: Competency Development and Learning Environment Strategies-A Systematic Review

5.3 How is Engineering Education 5.0 constructed through accreditation in engineering programmes within an Irish HEI?

As outlined in Chapter Three, this study employed Ball's (1993) policy analysis framework to integrate the data. Ball’s framework provided a means of tracing how the accreditation criteria were actively constructed, interpreted, and enacted through situated practices. Using this framework made visible how multiple actors and institutions negotiate meaning across the three contexts, shaping what Industry 5.0 comes to signify in Irish engineering education. This is particularly relevant for accreditation, which operates simultaneously as a policy instrument, a regulatory mechanism, and a set of practices negotiated within HEIs.

This analysis is organised around the results of the seven features of the Engineering Education 5.0 model in order to address the research question. For each feature, the findings draw together and synthesise results presented in Chapter Four across the three data sources: interviews with academics and accreditation stakeholders, the Engineers Ireland Accreditation Criteria (EIAC), and Self-Assessment Reports (SARs) submitted by a HEI. This synthesis enables a closer examination of how each feature is constructed through the accreditation process, identifying both the enabling and constraining dimensions of accreditation frameworks as they shape graduate attributes.

For each feature of Engineering Education 5.0, a brief table summarises the findings from each data source, alongside key tensions and gaps that emerge across the dataset. This facilitates comparison between espoused policy, institutional positioning, and lived experiences of implementation. By integrating these perspectives, the analysis shows how accreditation mediates the translation of Industry 5.0 competencies into educational practice.

The following discussion is situated within relevant literature, positioning the findings in relation to broader debates on accreditation, professional formation, and the evolving demands of engineering education.

5.3.1 Technical competency

The analysis highlighted technical competency as a consistently recognised priority across the interviews, the EIAC, and SARs, though the scope and explicitness of emerging technologies differ across sources. Table 5-2 provides a summary of the key findings on technical competency, highlighting areas of alignment and gaps across interviewees' perspectives, the EIAC, and the POs in the SARs.

Table 5-2: Summary of findings on technical competency

Theme	How Participants Positioned Technical Competency	How Technical Competency is Framed in the EIAC	How Technical Competency is Interpreted in SARs	Key Tensions / Gaps
Fundamentals	Strong emphasis on maintaining core engineering principles	Well integrated across NFQ levels	Comprehensive progression from Level 7–9	No significant gap
Data Analytics/Science	Seen as essential, already a core competency	Present but fragmented across POs	Progression from foundational (L7) to advanced (L9), but traditional in focus	Limited big data and predictive analytics
AI/Machine Learning	Identified as critical for future engineering roles	Not explicitly included in POs	Absent at all NFQ levels; only indirect coverage via data-handling	Major omission relative to industry needs
Automation/Robotics	Important for preparing graduates for emerging roles	Minimal reference; focus on conventional tools	Limited engagement; CAD and embedded programming noted, but no cobots/autonomous systems	Lack of structured inclusion of advanced automation
Alignment with Industry	Stress need for AI, automation, and advanced analytics	Slow to adapt to technological change	Traditional approaches dominate	Misalignment between accreditation/SARs and industry expectations

Technical competency in the Engineering Education 5.0 model emphasises integrating fundamental engineering principles with modern technologies to address contemporary challenges and foster innovation. As presented in Chapter Four, all three interviewees emphasised the importance of maintaining a strong foundation in fundamental engineering principles within engineering programmes. However, they stressed that accreditation, which has traditionally prioritised technical competencies, must evolve to incorporate emerging technologies. Interviewees identified AI, data analytics, and automation as critical fields to be included in the EIAC. While they believed that data analytics is already included as a core competency, the need to prepare students for AI-driven work environments and the integration of automation into engineering education was equally deemed essential by interviewees to enable graduates to transition into emerging roles shaped by these technologies.

Mirroring the observations of the interviewees, the EIAC reflects the emphasis placed on technical competency, particularly in integrating fundamental engineering principles within engineering programmes. The progressive development of technical skills across NFQ levels is well supported. The EIAC also addresses data analytics and data science, but AI and related fields, such as machine learning, are not explicitly included. While the importance of equipping students with proficiency in data science tools and techniques, including dataset analysis and simulations, is mentioned, the treatment of data science across the POs is fragmented. For instance, while it is strongly emphasised in PO1 (Knowledge & Understanding), it lacks consistent integration across other POs. This is important as engineers need to be able to handle large datasets, extract insights, and apply statistical modelling. While data science appears in PAs such as PA1 (Science & Mathematics) and PA3 (Software & Information Systems), there is no clear progression pathway through the NFQ levels from basic analytics to advanced data-driven decision-making, and key aspects such as AI, machine learning, and predictive analytics are largely absent.

The findings from the analysis of the POs of the SARs closely align with those of the EIAC. This was not an unexpected outcome, given that this mandatory section of the SAR is the most important part where the HEI provides a detailed explanation of its understanding of each PO as prescribed by the EIAC. Fundamental engineering principles are comprehensively detailed across all NFQ levels in the SARs. Core principles such as mathematics, data-handling, and problem-solving progress from theoretical understandings at Level 7 to applied, interdisciplinary problem-solving at Levels 8 and 9. Similarly, design principles evolve from basic tools and techniques to advanced, software-driven innovation and prototype testing. Investigation skills and systematic experimentation become increasingly sophisticated, preparing students for real-world engineering challenges.

Where the EIAC focuses on data science tools and techniques, the SARs similarly reflect the practical application of data analytics, with students advancing from foundational skills at Level 7 to complex database management and data-driven decision-making at Level 9. However, the approach remains largely traditional, focusing on statistical and mathematical tools rather than emerging trends such as big data or predictive analytics. For instance, data handling and digital tools are integrated into broader technical skills through CAD, digital design processes, and embedded programming. However, explicit references to advanced automation systems are minimal, and structured engagement with collaborative robotics (cobots) or autonomous systems is absent. References to AI are also notably lacking, mirroring its limited presence in the EIAC. AI is not explicitly addressed at any NFQ level, though foundational aspects like data-handling and analysis are well covered. However, there is no direct focus on AI-specific technologies or applications, such as machine learning or generative AI tools.

In summary, technical competency is consistently constructed around fundamental engineering principles, with clear alignment across the interviews, accreditation criteria, and the POs in the SARs. However, the findings reveal significant gaps in the treatment of emerging technologies. While data analytics is partially addressed, its fragmented and traditional focus limits its relevance to contemporary industry practices. AI, machine learning, and automation, repeatedly emphasised by interviewees as essential for future engineering practice, are almost absent from both EIAC and the POs in the SARs. This disjuncture reflects a tension between the safeguarding of fundamentals and the slow evolution of accreditation frameworks, leaving graduates potentially underprepared for the realities of an AI- and automation-driven engineering landscape.

5.3.1.1 Contextualising the findings within the existing literature

Recent scholarship reinforces and sharpens these observations. Balart and Shryock (2024) propose an AI-integration framework that positions AI as part of a human-centred learning architecture, embedding personalised pathways, interdisciplinary projects, and explicit ethical considerations, directly reflecting the gaps identified in EIAC and SARs. Supriya *et al.* (2024) similarly emphasise the enabling stack of Industry 5.0, AI/ML, big data, IoT, and digital twins, demonstrating multiple higher education use cases and underlining the lag in Irish accreditation frameworks. They also provide concrete examples of cobots and digital twins in engineering programmes, showing that integration is already delivering benefits in hands-on learning.

Pacher *et al.* (2024) and Koch *et al.* (2025) highlight the need to rebalance competence profiles, with empirical evidence suggesting an ideal mix of approximately 39% technological, 28% methodological, and 33% social skills, and over 80% of students and educators calling for curriculum updates. Caratozzolo *et al.* (2024) further identify design imperatives for new engineering education models, which include advanced technology integration, which is not yet embedded within the technical competency findings in the EIAC or SARs. Complementary perspectives reinforce these findings: Vogel, Lindner and Kratzsch (2023) demonstrate cobot integration in European programmes despite accreditation gaps, Gürdür Broo, Kaynak and Sait (2022) highlight barriers relating to faculty readiness and infrastructure, and Mourtzis, Angelopoulos and Panopoulos (2023) propose immersive approaches to bridge traditional and digital competencies. Collectively, these studies highlight the same central tension evident in the findings: technical competency is safeguarded at the level of fundamentals, but accreditation frameworks remain slow to evolve in explicitly embedding AI, automation, and human–machine collaboration, despite their clear feasibility and growing industry demand.

5.3.2 Sustainability

The analysis highlighted sustainability as widely recognised across the interviews, the EIAC, and SARs; however, its positioning differs, formally embedded as a pervasive theme in policy but unevenly distributed and progressed across programme outcomes in practice. This section examines how sustainability is articulated by interviewees, embedded in the EIAC, and operationalised in SARs, highlighting points of alignment as well as tensions in its integration, summarised in Table 5-3.

Table 5-3: Summary of findings in sustainability

Theme	How Participants Positioned Sustainability	How Sustainability is Framed in the EIAC	How Sustainability is Interpreted in SARs	Key Tensions / Gaps
Importance of Sustainability	Widely recognised as central to addressing global challenges	Embedded as PA7, aligned with SDGs and EE50	Evident in PO5 (ethics) and PO3 (design)	Shared recognition but uneven implementation
Form of Inclusion (PO vs PA)	Debate over whether sustainability should be a specific PO (fixed outcome) or a PA (pervasive practice)	Adopted as a PA following consultation debates	Reflected in SARs but not mandatory, as PAs need not be evidenced	Unresolved tension between fixed outcome and diffuse integration
Coverage Across POs	Differing views on extent of integration across the curriculum	Fragmented references (eg, PO5 ethics, limited in PO1 knowledge, PO4 investigation)	Strong in PO5 (ethics) and PO3 (design), weaker elsewhere	Uneven distribution across POs reduces coherence
Depth of Engagement	Viewed as requiring an evolving, interdisciplinary treatment	PA7 highlights net-zero, circular economy, ecological and societal awareness	Operationalised through legislation, LCA, renewable systems	Focus remains technical/legislative, less on systemic or societal perspectives

In this Engineering Education 5.0 model, sustainability integrates ecological and societal elements into engineering practices, balancing technological advancement with environmental management. It emphasises resource efficiency and awareness of long-term environmental and societal impacts, aiming to prepare students for sustainable engineering practices.

There was substantial evidence of a focus on sustainability across the complete dataset. All three interviewees recognised the importance of sustainability in engineering education, emphasising its role in addressing global challenges. They also agreed that sustainability should be integrated across the accreditation criteria rather than being included as a standalone topic in programmes. However, they had different opinions on how this should be done. One interviewee asserted that sustainability should be included as a PO, arguing that this would drive technological and social change in engineering. The other two interviewees believed that sustainability should be considered a PA as it is a broad and evolving concept, arguing that it is more of a pervasive practice than a fixed outcome. This tension, articulated by the interviewees, echoed stakeholder debates during the EIAC development consultation phase, during which, according to the interviewees who were in attendance, it was debated whether sustainability should be a specific PO or, as ultimately decided, a pervasive theme incorporated as a PA. The inclusion of sustainability as a PA reflects the ongoing calls for sustainability to be embedded across curricula rather than treated as an isolated requirement.

The 2021 EIAC demonstrates progress by embedding sustainability in the accreditation framework through a new PA. Specifically, PA7 addresses key concepts such as net-zero carbon, the circular economy, ecological and societal elements, resource efficiency, and environmental impact awareness, aligning with both the SDGs[15] and the Engineering Education 5.0 model. However, the tensions observed among the interviewees' perspectives are also evident in the EIAC analysis, which showed a fragmented approach to sustainability across the POs. For instance, while elements of sustainability are included in PO5 (Ethics and Professional Responsibility), reflecting the profession's ethical obligations to society and the environment, it does not explicitly detail strategies for integrating resource efficiency, reducing ecological footprints, or achieving long-term sustainability goals. Furthermore, PO1 (Knowledge) and PO4 (Investigation) lack specific references to resource management or the long-term societal and environmental impacts of engineering decisions, which are important elements of sustainability in engineering education.

The SARs build on the EIAC by illustrating how sustainability is operationalised in programmes. However, although the inclusion of sustainability through PA7 was found in the EIAC, the lack of a mandatory requirement for programmes to demonstrate compliance with PAs in the SARs places the responsibility for demonstrating sustainability solely on the POs. A key finding is the uneven representation of sustainability across the POs in the SARs, mirroring the fragmented approach observed in the EIAC. Attention to sustainability is strongly evident in PO5 (Ethics and Professional Responsibility) and PO3 (Design). PO5 in the SARs introduces students to safety protocols, environmental legislation, and advanced sustainability assessments, reflecting the Engineering Education 5.0 model's emphasis on balancing technological advancement with environmental and societal responsibilities. The focus on legislative frameworks and sustainability assessments also helps develop engineers who can navigate and contribute to sustainable practices within both societal and ecological contexts. Evidence of sustainability is also evident in PO3, which emphasises life-cycle analysis, resource efficiency, and renewable energy systems, elements that support the Engineering Education 5.0 model's priority on technological advancements that minimise environmental impact. However, the remaining POs primarily focus on technical solutions, such as energy efficiency and renewable energy systems, without integrating broader interdisciplinary or societal perspectives.

In summary, sustainability is widely recognised across the interviews, the EIAC, and SARs as a vital dimension of engineering education. However, the ways in which it is positioned remain uneven and contested. While the EIAC formally acknowledges sustainability through PA7, its fragmented presence across the POs limits coherent progression. Similarly, SARs demonstrate strong engagement in areas such as ethics and design but provide less evidence of integration across

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[15] https://sdgs.un.org/goals

the full range of outcomes. This uneven treatment reflects a broader tension: sustainability is valued as a principle yet is inconsistently embedded as practice, leaving its role in shaping graduate competencies only partially realised.

5.3.2.1 Contextualising the findings within the existing literature

The findings of this study align with the work of Mazur and Walczyna's (2022) argument that engineering students must develop comprehensive sustainability competencies encompassing knowledge, ethical values, and systems thinking. Findings in this study support their observation of a gap in engineering education where sustainability is presented as a technical challenge rather than an integrated, interdisciplinary concern. As in their work, this study highlights the persistent tendency to present sustainability primarily as a technical challenge rather than as an integrated, interdisciplinary concern. Byrne (2023) similarly stresses the need for accreditation bodies to continue adapting, ensuring sustainability is recognised as an integral component of engineering education rather than an ancillary theme, a position reflected in one interviewee's call for sustainability to be treated as a distinct PO.

More recent scholarship reinforces and extends these perspectives. Kovari (2024) argues for a transformation of engineering pedagogy in Industry 5.0, embedding sustainability alongside lifelong learning, human-centred design, and transdisciplinarity as core pillars of education. Luna, Chong and da-Silva-Ovando (2024) further emphasise the centrality of sustainability to Education 5.0, framing it as a pedagogical transformation that must align with the SDGs and balance ecological and societal well-being. Their work underscores that sustainability requires not only curricular inclusion but also scalability and long-term viability in educational practice. Building on this, Galatro and Chakraborty (2025) provide concrete strategies for embedding sustainability within undergraduate curricula through vertical scaffolding across levels, integration of circularity indicators, and the use of life-cycle assessment tools, demonstrating that sustainability can be systematically operationalised rather than treated as diffuse or peripheral.

Taken together, this literature supports the study's finding that while sustainability is widely valued, accreditation frameworks and institutional practices continue to approach it unevenly and in fragmented ways. The broader scholarship strengthens the case for moving beyond partial references to sustainability in ethics or design, towards its explicit recognition as a core engineering competency, aligned with both global sustainability goals and the transformative ambitions of Engineering Education 5.0.

5.3.3 Ethics and social impact

This Engineering Education 5.0 model positions ethics and social responsibility as foundational to engineering practice, emphasising integrity, data privacy, and consideration of the human and environmental consequences of technological innovation. The analysis highlighted ethics and social impact consistently across the interviews, the EIAC, and SARs, though integration beyond PO5 into technical and managerial domains is less systematic and variably evidenced, as summarised in Table 5-4.

Table 5-4: Summary of findings in ethics and social impact

Theme	How Participants Positioned Ethics	How Ethics is Framed in the EIAC	How Ethics is Interpreted in SARs	Key Tensions / Gaps
Centrality of Ethics	Framed as a foundational pillar; engineers as agents of social change.	Strong emphasis in PO5 .	PO5 strongly represented; progression from Level 7 to 9.	Shared recognition but uneven embedding across curriculum.
Scope of Integration	Advocated ethics across multiple POs, not only PO5.	Ethics present in PO3, PA6 (Societal & Business), PA7 (Sustainability).	Ethics present in technical POs (safety, compliance) but largely siloed.	Ethics not consistently integrated into technical/non-technical POs.
Treatment of Emerging Technologies	Concern over gaps in addressing ethical dilemmas in digital/AI contexts.	PO5 includes data and tech ethics, but limited in PO1 and PO4	Limited explicit engagement with digital ethics; focus more on compliance and safety.	Lack of systematic treatment of AI/data ethics across framework.
Implementation Challenges	Highlighted institutional/structural barriers; need for programme design and industry alignment.	EIAC updates (2021) seen as progress but fragmented in technical POs.	Ethics developed through case studies, compliance tasks, but weak interdisciplinarity.	Ethics often treated as a standalone component, not embedded holistically.
Professional/Managerial Contexts	Recognised importance for governance and resource allocation.	PO8 (Management) includes compliance and legal principles.	PO8 reflects compliance focus, but lacks guidance on ethical dilemmas in governance.	Ethics in management framed narrowly around compliance, not broader dilemmas.

As outlined in Chapter Two, ethics was first introduced as a standalone PO in the 2014 version of the EIAC. The findings of this study demonstrate that ethics is consistently incorporated across accredited programmes, albeit to varying degrees. The interviews provide insights into the decision-making process during the development of the 2021 EIAC, particularly regarding the integration of ethics and social impact into accreditation criteria. The perspectives shared by the interviewees align closely with the principles outlined in Engineering Education 5.0, emphasising the role of engineers in addressing ethical dilemmas and societal challenges. Interviewees unanimously supported embedding ethical awareness throughout engineering curricula, framing ethics as a foundational pillar of engineering practice, and emphasising the need for graduates to critically assess the human and environmental impact of their work and to act as agents of social change. To this end, they strongly endorsed the enhancement of PO5 (Ethics and Professional Responsibility) as a dedicated PO. However, they also advocated for a more comprehensive integration of ethics across multiple POs to ensure that ethical considerations permeate both technical and non-technical aspects of engineering education. Institutional and structural barriers were also acknowledged as persistent challenges, particularly in ensuring the effective implementation of ethical principles in professional practice. Interviewees highlighted the necessity for deliberate programme design, strong industry alignment, and ongoing revisions to accreditation frameworks. While the updates in the 2021 EIAC were perceived as a step forward, interviewees noted gaps in how ethics is integrated within technical POs and how emerging technologies are addressed.

The 2021 EIAC reflects many of the priorities outlined by the interviewees, particularly in the treatment of PO5. This outcome places significant emphasis on professional integrity, societal impact, and sustainability, reinforcing the commitment to embedding ethics in engineering education. PO5 also includes ethical considerations related to the use of data and technology, which is increasingly relevant in the Industry 5.0 era, where the interaction between humans and digital systems is becoming more complex (Breque, De Nul and Petridis, 2021). Additionally, ethical aspects are incorporated within PO3 (Design), as well as in PAs such as PA6 (Societal & Business Context) and PA7 (Sustainability), encouraging multidisciplinary collaboration and problem-solving with a sustainability focus. However, ethics remains inconsistently embedded across technical POs, particularly PO1 (Knowledge and Understanding) and PO4 (Investigation), which prioritise technical skills but offer limited explicit engagement with ethical decision-making in engineering practice. Although PO8 (Engineering Management) introduces compliance and legal principles, it does not provide clear guidance on ethical dilemmas related to resource allocation and project governance.

The SARs further illustrate how ethical awareness is developed across NFQ levels. PO5 is strongly represented, showing evidence of a progressive development from foundational ethical principles at Level 7 to more complex evaluations of societal and environmental implications at Levels 8 and 9. However, despite its significance, ethics is unevenly integrated across other POs. While technical POs (PO1–PO4) incorporate ethical considerations in areas such as material selection, safety standards, and regulatory compliance, they tend to lack an interdisciplinary perspective that connects ethics to broader societal and technological contexts. Conversely, non-technical POs (PO6–PO8) exhibit limited engagement with ethics and social impact, reinforcing the notion that ethics is often siloed within dedicated course components rather than embedded holistically across the curriculum.

In summary, ethics and social impact are firmly recognised as fundamental within engineering education, with the interviews, the EIAC, and SARs all emphasising their importance. Yet the findings reveal persistent unevenness in how these principles are embedded across accreditation criteria and POs in the SARs. While PO5 provides a strong foundation and demonstrates clear progression across NFQ levels, ethical considerations in technical and managerial POs remain limited, often reduced to compliance or safety rather than broader engagement with societal and technological dilemmas. This fragmented integration highlights a tension between acknowledging ethics as a central pillar of professional responsibility and the challenges of embedding it holistically across technical and non-technical domains.

5.3.3.1 Contextualising the findings within the existing literature

The findings of this study resonate with broader debates in engineering education. Martin, Conlon and Bowe (2021) observe that while ethics is increasingly present in curricula, it is often siloed rather than woven into applied technical learning, mirroring the uneven embedding found across POs and SARs. Gürdür Broo, Kaynak and Sait (2022) sharpen this tension by stressing that Industry 5.0 requires ethical frameworks attuned to human–machine collaboration, automation, and data privacy, areas where the EIAC and SARs currently lack systematic engagement.

Recent work further reinforces these concerns. Balart and Shryock (2024) propose a human-centred AI integration framework that makes ethical reflection inseparable from technical training, emphasising personalised learning pathways and interdisciplinary collaboration. Koch *et al.* (2025) provide empirical evidence that educators and students converge on the need to rebalance competence profiles, with ethics and social impact positioned alongside technical and methodological skills. Firescu (2025) extends this perspective by arguing that sustainability-oriented ethics cannot be realised without cultivating soft skills, ergonomics, and transformative learning experiences that enable engineers to become active agents of social responsibility. Similarly, Lagorio and Cimini (2024) show how learning factories can immerse students in socio-technical dilemmas, making the ethical and social consequences of design and production choices explicit. Kovari (2024) situates these shifts within a broader pedagogical transformation, advocating transdisciplinary, lifelong learning approaches where ethics are integrated across all domains rather than appended as compliance tasks. Taken together, these perspectives reinforce this study's conclusion that accreditation frameworks and institutional practices need to move beyond compliance-based ethical education, embedding ethics holistically across technical, social, and managerial domains to prepare engineers for the complex responsibilities of Industry 5.0.

5.3.4 Collaboration

Collaboration in engineering education is framed as a core competency that enables graduates to operate effectively in diverse, multidisciplinary contexts. Within the Engineering Education 5.0 model, collaboration encompasses teamwork, interdisciplinary problem-solving, stakeholder engagement, and adaptability to technological change. The analysis highlighted collaboration as a consistently recognised competency across the interviews, the EIAC, and SARs, though the ways in which it is emphasised differ. This section explores how collaboration is articulated in the interviews, embedded within the EIAC, and operationalised through the POs in the SARs as summarised in Table 5-5.

Table 5-5: Summary of findings in collaboration

Theme	How Participants Positioned Collaboration	How Collaboration is Framed in the EIAC	How Collaboration is Interpreted in SARs	Key Tensions / Gaps
Centrality of Collaboration	Framed as essential for addressing modern engineering challenges; teamwork positioned as foundational.	Explicitly embedded in PO6 (Teamwork & Lifelong Learning) and PO7 (Communication).	Progressive development of teamwork across NFQ levels.	Strong emphasis on teamwork, but broader collaboration less developed.
Teamwork vs. Interdisciplinary Collaboration	Emphasised adaptability across cultural and disciplinary boundaries.	Indirect references in PO3 (Design) and PO4 (Investigation).	Group projects and capstones develop teamwork; limited interdisciplinary engagement.	Interdisciplinary collaboration underemphasised compared to teamwork.
Stakeholder Engagement	Noted limited engagement with industry and community partners.	PO8 (Engineering Management) focuses on team collaboration, not external partnerships.	Some engagement with industry professionals; limited wider stakeholder collaboration.	Stakeholder engagement remains peripheral.
Adaptation to Technological Change	Identified need to adapt collaboration to technological advancements.	EIAC offers little guidance on evolving collaborative practices.	Technology integrated into activities but not linked to rapid technological change.	Weak link between collaboration and emerging technologies.

The interviewees stressed the importance of collaboration as a key competency for engineering graduates, identifying teamwork as essential for addressing modern engineering challenges in diverse and multidisciplinary environments. Group projects and collaborative capstone activities were highlighted as opportunities for students to develop practical skills like task management, budgeting, and resource allocation. Interviewees also noted the significance of frameworks such as the Washington, Sydney, and Dublin[16] Accords which emphasise collaboration and integrate it into accreditation criteria. They argued that graduates must be adaptable, inclusive, and able to collaborate effectively across cultural and disciplinary boundaries. However, interviewees felt that while teamwork was well-established, there was limited emphasis on interdisciplinary collaboration and broader stakeholder engagement, such as partnerships with community organisations or industry representatives.

The EIAC reflects many of the priorities raised during the interviews, particularly the emphasis on teamwork and communication. Collaboration is explicitly addressed through several POs and PAs, most notably and unsurprisingly in PO6 (Teamwork and Lifelong Learning). The EIAC provides a vehicle for embedding collaboration, highlighting teamwork as a critical competency for graduates. Students are encouraged to work effectively in teams, fostering skills such as communication, adaptability, and conflict resolution. PO7 (Communication), for instance, reinforces the role of collaboration by equipping students with the ability to engage with diverse audiences and present technical findings effectively. Indirect references to collaboration can also be found in PO3 (Design) and PO4 (Investigation), where interdisciplinary engagement is encouraged during research and design processes. However, the EIAC has some limitations in this area. While teamwork is strongly emphasised, explicit references to interdisciplinary collaboration

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[16] https://www.internationalengineeringalliance.org

and external stakeholder engagement are limited. For example, although the new PO8 (Engineering Management) addresses collaboration within project teams, it does not explicitly incorporate partnerships with industry or community organisations. Additionally, there is little guidance on how collaboration should adapt in response to rapid technological advancements, an essential aspect of Engineering Education 5.0.

The SARs provide clear evidence of how collaboration is operationalised within engineering programmes, reflecting the content of the EIAC in relation to PO6 (Teamwork and Lifelong Learning) and PO7 (Communication). The findings indicate that collaboration is progressively developed across the NFQ levels, reflecting the structured approach outlined in the EIAC. This development begins with foundational collaboration skills involving group projects and practical activities. Collaboration is developed progressively across the NFQ levels, starting with foundational skills through group projects and moving toward more structured, interdisciplinary, team-based projects that simulate real-world engineering challenges. Students engage with industry professionals, gaining insights into stakeholder engagement. However, limitations exist. Like the EIAC, there are few references to interdisciplinary problem-solving or external stakeholder engagement. Instead, collaboration is primarily confined to internal academic contexts. Additionally, while technology is integrated into collaborative activities, the adaptation of these tools to meet rapid technological advancements is not thoroughly discussed.

In summary, collaboration is firmly embedded in engineering education, with teamwork well supported across accreditation criteria and institutional practice. The EIAC and SARs demonstrate clear progression in how students develop collaborative skills, particularly through group projects and capstone activities. However, the findings also reveal important limitations. Interdisciplinary collaboration is less visible, stakeholder engagement beyond academic settings remains peripheral, and the adaptation of collaborative practices to technological change is underdeveloped. These gaps suggest that while collaboration is widely recognised as essential, its treatment is uneven, remaining primarily focused on teamwork rather than encompassing the broader, more complex forms of collaboration envisaged in the Engineering Education 5.0 model.

5.3.4.1 Contextualising the findings within the existing literature

The study's finding that teamwork is well-established but interdisciplinary collaboration remains limited reflects wider patterns identified in the literature. Gürdür Broo, Kaynak and Sait (2022) argue that engineering education must evolve to prioritise transdisciplinary collaboration, moving beyond traditional disciplinary silos. They emphasise that the convergence of fields such as AI, robotics, and sustainability requires engineers who can function effectively in cross-functional teams. Similarly, Sangwan and Venugopal (2022) observe that while students increasingly recognise the need for interdisciplinary collaboration, they often lack exposure to problem-solving contexts that involve multiple disciplines.

Recent scholarship extends these insights, particularly in relation to stakeholder engagement and technology-enabled collaboration. Golser *et al.* (2025) stress the importance of embedding stakeholder collaboration at the earliest stages of curriculum design, ensuring that engineering education reflects the demands of human-centric, sustainable, and resilient value chains. Caratozzolo *et al.* (2024) likewise argue that preparing engineers for Industry 5.0 requires an interdisciplinary approach that dissolves boundaries between disciplines while integrating human-centred and technological competencies. Meanwhile, emerging studies on human–AI collaboration highlight that digital technologies are reshaping the very nature of collaborative practice, requiring graduates to learn how to co-create with intelligent systems as well as with peers.

Taken together, this body of work reinforces the study's findings: while teamwork is securely embedded within accreditation frameworks and programmes, gaps remain in interdisciplinary collaboration, stakeholder engagement, and the integration of technology into collaborative practices. The broader literature consistently calls for a more comprehensive and transdisciplinary approach, aligning with the collaborative imperatives of Engineering Education 5.0.

5.3.5 Educational approach

The Engineering Education 5.0 model positions educational approach around continuous learning, adaptability, and inclusivity, emphasising lifelong learning and the flexibility to respond to societal and technological change. The analysis highlighted lifelong learning and adaptability as consistently recognised across the interviews, the EIAC, and SARs, while personalisation and inclusivity receive comparatively limited and uneven attention. This section examines how educational approaches are articulated by participants, embedded within the EIAC, and demonstrated in SARs, identifying points of convergence as well as gaps in practice, as summarised in Table 5-6.

Table 5-6: Summary of findings in educational approach

Theme	How Interviewees Positioned Educational Approach	How Educational Approach is Framed in the EIAC	How Educational Approach is Interpreted in SARs	Key Tensions / Gaps
Lifelong Learning	Framed as fundamental; essential for navigating evolving engineering practice.	Explicit in PO6.	Strong progression from foundational skills to advanced professional practice.	Consistently embedded and aligned.
Self-Directed Learning	Advocated for curricula that foster student ownership of learning.	Reinforced through emphasis on CPD and responsibility for ongoing learning.	Evident in independent research, projects, and reflective tasks.	Well supported but uneven across programmes.
Adaptability	Positioned as critical for emerging technologies and complex challenges.	Present in PO2 and PO3, tackling complex/ill-defined problems.	Demonstrated through flexible problem-solving and independent projects.	Adaptability mostly framed in technical contexts; limited reference to societal change.
Personalisation	Limited discussion; little emphasis on tailoring to individual goals.	Not explicitly addressed (outside EI's remit).	Some evidence through open-ended projects, but not systematically embedded.	Lack of explicit strategies for personalised pathways.
Inclusivity	Largely absent from interview discourse.	Underdeveloped; limited reference in accreditation.	Implied but not explicitly articulated in SARs.	Weak integration of inclusivity across accreditation and curricula.
Mode of Delivery	Recognised opportunities in online/remote learning post-COVID, especially for CPD.	Not within scope of EI accreditation.	Examples of blended/remote approaches evident but not consistently highlighted.	Tension between online flexibility and hands-on experience.

The interviews provided perspectives on how educational approaches are understood and prioritised within engineering education. Interviewees consistently stressed the importance of lifelong learning as a fundamental principle, emphasising its critical role in equipping graduates to navigate the dynamic and ever-evolving nature of engineering practice. They also emphasised a need to foster self-directed learning, advocating for curricula that enable students to take ownership of their professional development. This was deemed essential in ensuring graduates remain adaptable in the face of emerging technologies and complex challenges. Additionally, interviewees identified post-COVID advancements in online learning as an opportunity to expand access to part-time and remote learners, particularly for CPD. However, they also stressed the need to balance online delivery with hands-on, practical experience, which remains a cornerstone of engineering education. Although there was a clear emphasis on lifelong learning in the interviews, there was limited discussion about personalisation and inclusivity in engineering education. While adaptability was recognised as important, the interviews revealed a significant gap in accreditation for explicit strategies for tailoring education to meet individual learner needs and accommodating diverse backgrounds.

The EIAC reinforces many of the priorities identified in the interviews, particularly regarding lifelong learning and adaptability. The emphasis on lifelong learning is most evident in PO6 (Teamwork and Lifelong Learning), which highlights the importance of CPD and self-directed learning. Graduates are expected to take responsibility for their ongoing education, aligning well with the definition of this feature. Additionally, the EIAC promotes adaptability through several POs, such as PO2 (Problem Solving) and PO3 (Design), which encourage students to address complex and ill-defined problems while navigating interconnected systems. However, the EIAC exhibits some limitations. While flexibility through diverse career outcomes is supported, the accreditation criteria do not explicitly address personalisation in learning pathways to cater to individual goals and aspirations. This is not unexpected as approaches to pedagogy and delivery modes, such as online or blended, are not part of the remit of Engineers Ireland. Similarly, the focus on inclusivity is underdeveloped, with limited guidance on creating equitable learning environments that accommodate diverse student populations. Furthermore, while the EIAC emphasises adaptability in technical contexts, it lacks explicit reference to broader societal changes, limiting its alignment with the vision of Engineering Education 5.0.

Through the POs submitted for accreditation, the SARs provide detailed evidence of how educational approaches are put into practice across engineering programmes, reflecting the structured approach outlined in the EIAC. They demonstrate a clear progression in the development of lifelong learning, self-directed learning, and adaptability across NFQ levels. Foundational skills in lifelong and self-directed learning are introduced, focusing on acquiring core knowledge and managing independent learning tasks. Finally, lifelong learning is embedded in advanced professional practice, where students undertake independent research, critically evaluate their learning, and demonstrate flexible problem-solving in response to complex engineering scenarios. While the SARs provide strong evidence of lifelong learning and adaptability, evidence of personalisation and inclusivity is limited. Open-ended projects and independent research offer opportunities for customisation, but strategies to tailor learning to individual needs are not clearly articulated. Furthermore, while inclusivity is implied through broader educational goals, there is little evidence of efforts to ensure diverse learning needs are met. These gaps echo the limitations identified in the EIAC, suggesting a need for more deliberate integration of personalisation and inclusivity into accreditation criteria.

In summary, lifelong learning and adaptability are consistently recognised and embedded across interviews, accreditation criteria, and SARs, reflecting their importance within the Engineering Education 5.0 model. These principles are well supported through structured progression, self-directed learning opportunities, and project-based activities that prepare students for evolving professional contexts. However, the findings also highlight notable gaps. Personalisation and inclusivity are only weakly articulated, with limited strategies for tailoring education to individual needs or addressing diverse learner backgrounds. Similarly, while adaptability is emphasised in technical contexts, it is not consistently linked to broader societal change. These gaps suggest that while current approaches provide a solid foundation in lifelong and adaptive learning, they fall short of fully realising the inclusive and personalised vision of Engineering Education 5.0.

5.3.5.1 Contextualising the findings within the existing literature

The emphasis on lifelong learning and adaptability in this study aligns with Sangwan and Venugopal's (2022) framework, which promotes project-based and self-directed learning as foundations for lifelong learning habits. Similarly, Gürdür Broo, Kaynak and Sait (2022) highlight structural barriers to embedding personalisation in engineering education, echoing the study's finding that while adaptability is increasingly recognised in accreditation, tailored learning pathways remain underdeveloped.

Recent work strengthens these observations. Kovari (2024) argues for a pedagogical shift towards just-in-time learning and microlearning, positioning lifelong learning as central to Industry 5.0 readiness while also emphasising inclusivity and flexibility in delivery. Complementing this, Lagorio and Cimini (2024) demonstrate the potential of learning factories as immersive environments that embed continuous learning and Industry 5.0 competencies, offering scalable models that bridge academic and industrial contexts. At a systemic level, reviews of Engineering Education 5.0 emphasise the need for educational approaches that combine technological fluency with human-centricity and transdisciplinarity, underlining the importance of aligning pedagogy with emerging socio-technical demands. Yet, as the findings confirm, accreditation frameworks continue to lag in formally embedding inclusivity and personalisation, despite calls for student-centred models (Al-Emran and Al-Sharafi, 2022) and structured learning pathways (Lantada, 2020). Overall, the literature reinforces the study's conclusion: while lifelong learning and adaptability are well supported, significant progress is still needed to embed inclusivity, personalisation, and technologically enhanced delivery into accreditation and practice.

5.3.6 Global and Cultural Perspectives

Global and cultural perspectives in engineering education are shaped by the ways accreditation standards, institutional practices, and professional expectations position graduates for international mobility and cultural engagement. The Engineering Education 5.0 model frames this competency as extending beyond technical expertise to include an awareness of global challenges, the ability to collaborate across cultural divides, and the preparation of graduates to participate in the international engineering community. The analysis highlighted global perspectives as consistently recognised across the interviews, the EIAC, and the POs in the SARs, primarily via alignment with international standards, whereas cultural competence and cross-cultural collaboration are less explicitly developed, as summarised in Table 5-7.

Table 5-7: Summary of findings in global and cultural perspectives

Theme	How Intervieews Positioned Global & Cultural Perspectives	How Framed in the EIAC	How Interpreted in SARs	Key Tensions / Gaps
International Mobility	Strongly emphasised as essential for employability; alignment with global standards seen as critical.	EIAC ensures programmes align with Washington, Sydney, Dublin Accords and global regulatory frameworks.	International standards and regulations embedded in curricula (e.g., industry standards, CAD, sustainability frameworks).	Well established across all levels; little contestation.
Cultural Competence	Two participants viewed as essential; one saw it as developing organically in practice.	PA6 references multicultural considerations; PA7 incorporates SDGs.	Some placements in diverse teams; design/communication modules reference global practices.	Not systematically embedded; limited cross-cultural training.
Management & Governance	Little focus in interviews.	PO8 (Engineering Management) does not address global project management or international governance.	Limited evidence of global management or transnational collaboration.	Gap in preparing graduates for international leadership roles.
Overall Balance	Recognition of importance of global frameworks; mixed views on cultural competence.	Emphasis on global regulatory and sustainability frameworks; weaker on intercultural skills.	Strong in technical/regulatory alignment, weaker in cross-cultural communication.	Tension between compliance with global standards and developing cultural adaptability.

The interviews highlight the strong emphasis on international mobility in engineering education, with interviewees stressing the importance of aligning Irish qualifications with global standards to enhance graduate employability. Interviewees saw the Washington, Sydney, and Dublin Accords as key frameworks facilitating the international recognition of engineering degrees. Beyond accreditation, the interviewees considered cultural awareness as increasingly important in a diverse profession. While two viewed cultural competence as essential, the other prioritised technical skills, suggesting cultural competence should develop organically through professional experience rather than formal education.

The EIAC reflect many of the priorities identified in the interviews, particularly in relation to international standards and sustainability goals. The accreditation criteria ensure that engineering programmes align with global regulatory frameworks and industry expectations, reinforcing the emphasis on international mobility. The EIAC also emphasises global perspectives within sustainability and ethics, reinforcing the need for engineers to engage with global challenges. For example, PA6 requires students to understand multicultural considerations and global constraints in their professional practice, and PA7 incorporates the UN SDGs. Despite this, little attention is accorded to the development of cultural competence and interdisciplinary collaboration. The EIAC does not explicitly require students to develop skills in cross-cultural communication or international teamwork. Furthermore, technical POs prioritise engineering knowledge and do not require students to apply their expertise in a global or cultural context. The new PO8 (Engineering

Management) does not address global project management, international governance structures, or the role of engineers in transnational collaborations.

The SARs provide a practical implementation of how global and cultural perspectives are applied within engineering programmes. The evidence suggests that while international standards and global regulations are consistently incorporated into curricula, systematic engagement with cross-cultural collaboration is not. There is strong evidence of global awareness in technical and regulatory contexts whereby students engage with international industry standards, hazard analysis techniques, and sustainability frameworks, thus ensuring they graduate with an understanding of global best practices. Furthermore, some programmes include placements in diverse teams, offering students exposure to professional settings with a variety of cultural and disciplinary perspectives. In design and communication modules, for example, students are encouraged to apply international best practices in CAD software, technical drawings, and research presentation formats, ensuring their work meets global industry expectations. Despite these strengths, the SARs echo the gaps identified in the EIAC and interviews. Students receive little input on cross-cultural communication and international problem-solving. A consistent strategy to prepare students to navigate cultural differences in professional settings, as well as interdisciplinary collaboration with international teams, was not found to be embedded within programmes. This suggests that while students are trained to comply with global engineering standards, they are not necessarily equipped with the interpersonal and cultural adaptability required to work effectively across borders.

In summary, global perspectives are firmly embedded in engineering education through accreditation frameworks and programmes, with strong alignment to international standards and regulatory frameworks, ensuring graduate mobility. However, cultural competence and cross-cultural collaboration are less consistently addressed. While some opportunities exist through placements and exposure to international best practices, these are not systematically embedded within accreditation or institutional programmes. This highlights a tension between preparing graduates to comply with global standards and equipping them with the cultural awareness and adaptability needed to engage effectively in diverse, international professional contexts.

5.3.6.1 Contextualising the findings within the existing literature

These findings resonate strongly with the wider literature, which similarly observes that while international mobility is well established, cultural competence remains underdeveloped in engineering education (Al-Emran and Al-Sharafi, 2022; Gürdür Broo, Kaynak and Sait, 2022). Lantada (2020) suggests that global accords and accreditation indirectly promote best practices in ethics, sustainability, and international teamwork, yet stop short of explicitly mandating cultural training. This reflects the study's conclusion that standardisation is prioritised over adaptability to diverse cultural contexts, despite the growing recognition of the latter's importance.

Recent scholarship reinforces and extends these points. Koch *et al.* (2025) demonstrate through large-scale survey evidence that a balanced competence mix for Industry 5.0 requires deliberate development of global citizenship and cultural capabilities alongside technical proficiency. Similarly, Caratozzolo *et al.* (2024) argue that universities best positioned to prepare graduates for Industry 5.0 are those embedded in international alliances, where interdisciplinary curricula are coupled with exposure to global challenges and diverse perspectives. This echoes the study's observation that ENAEE has strengthened cross-border collaboration in higher education, but also underscores the need for structured, intentional approaches to cultural adaptability.

Complementing this, Luna, Chong and da-Silva-Ovando (2024) highlight that Education 5.0 must explicitly link technological innovation with cultural and social well-being, proposing omnidigital education and ICT-enabled international collaboration as pathways to broaden cultural perspectives within engineering curricula. Together, these perspectives suggest that while Irish accreditation aligns with international standards, it risks lagging global trends where cultural adaptability, interdisciplinary collaboration, and human-centred values are being deliberately embedded as core competencies for Industry 5.0.

5.3.7 Holistic and human-centric

Holistic and human-centric approaches in engineering education are framed through the integration of technical expertise with an explicit concern for societal and interpersonal dimensions. The Engineering Education 5.0 model emphasises the development of technologies that serve humanity and improve quality of life, while also recognising the importance of inclusivity, accessibility, and diverse learning needs. The analysis highlighted human centricity as consistently endorsed across the interviews, the EIAC, and SARs, yet concrete mechanisms for inclusivity and accessibility remain variably specified and implemented as summarised in Table 5-8.

Table 5-8: Summary of findings in holistic and human-centricity

Theme	How Participants Positioned Holistic & Human-Centric	How Framed in the EIAC	How Interpreted in SARs	Key Tensions / Gaps
Integration of Technical & Human Contexts	Strong support for embedding technical skills within human and societal contexts	PO3 and PO5 emphasise human-centred, sustainable solutions	Evidence across modules encouraging socially responsible engineering	Broad alignment, but varied in practice
EDI and Inclusivity	Divergent views: one saw engineering as meritocratic; others stressed growing employer demand for inclusivity	Acknowledges inclusivity but lacks concrete strategies for universal accessibility	EDI considerations appear in PO5 and PO6; awareness of equal opportunities evident	Inclusivity recognised but not systematically embedded
Graduate Preparedness	Emphasised need for interpersonal, ethical, and holistic skills alongside technical expertise	Accreditation highlights societal impact and professional responsibility (PO5)	Evidence of emotional intelligence and inclusivity in teamwork and ethics modules	Tension between principle and consistent application
Leadership & Management	Stressed growing importance of project coordination and people management; PO8 cited as evidence	PO8 reflects leadership and organisational competencies	Examples of teamwork and management skills being developed across NFQ levels	Leadership competencies embedded, but inclusivity less systematically addressed
Accessibility & Diverse Needs	Participants highlighted user-centred design and accessibility as important concerns	Inclusivity promoted but without mechanisms to address structural barriers	Limited evidence of structured strategies to ensure accessibility for diverse learners	Gap between recognition of inclusivity and practical implementation

The interviews indicated strong support for integrating technical skills within a human and societal context in engineering education, and the interviewees perceived that accreditation criteria reflect this emphasis. However, the interviewees had diverging perspectives regarding formal EDI initiatives. While one interviewee viewed engineering as inherently meritocratic and questioned the necessity of structured diversity programmes, the others emphasised that employers increasingly value inclusivity, thus reinforcing the importance of interpersonal and holistic skills. These interviewees stressed that accreditation was evolving to produce well-rounded graduates, balancing technical expertise with ethical awareness, communication, and teamwork. The evolving role of engineers as managers was emphasised, particularly in relation to project coordination and people management skills. According to one interviewee, the introduction of PO8 (Engineering Management) serves as a clear example of how accreditation criteria are continuously adapted to reflect industry demands, ensuring that graduates are equipped with the necessary leadership and organisational competencies required in professional practice. Moreover, accessibility and inclusivity emerged as key concerns among the interviewees, who argued for the adoption of user-centred design principles to accommodate diverse societal needs.

The EIAC aligns closely with the definition of holistic and human-centric aspects of Engineering Education 5.0, particularly in integrating technical knowledge with an understanding of human and societal needs. Across the POs and PAs, there is clear evidence of a commitment to ethical responsibility, inclusivity, and sustainability. A notable strength of the EIAC is its efforts to stress the societal impact of engineering, ensuring students develop technology that improves quality of life (PO5, Ethics and Professional Responsibility), as well as reinforcing human-centric, sustainable solutions (PO3, Design), yet challenges remain in fully embedding inclusivity within accreditation criteria. Diverse learning needs are acknowledged, but lack concrete strategies for universal accessibility. Similarly, inclusive design is promoted without addressing structural barriers for under-represented groups. Overall, the accreditation criteria recognise inclusivity but require clearer, actionable strategies to embed accessibility, equity, and social responsibility systematically.

While the EIAC establishes a platform for integrating human-centric principles into engineering education, its effectiveness ultimately depends on how these criteria are implemented within academic programmes. The SARs provide insight into this application and offer strong evidence of a commitment to holistic and human-centric engineering education. A notable finding is the integration of EDI principles across NFQ levels. PO5 (Ethics and Professional Responsibilities) incorporates diversity considerations, fostering an awareness of equal opportunities and inclusive professional practice. Evidence of emotional intelligence and social inclusivity is also present, reinforcing the importance of collaborative and ethical decision-making. The SARs further support the development of socially responsible engineers. PO4 (Investigation) encourages students to engage with diverse perspectives and present findings to non-engineering audiences, promoting cross-disciplinary communication. Similarly, PO6 (Teamwork and Lifelong Learning) emphasises the importance of inclusive teamwork, ensuring students develop the interpersonal skills necessary for diverse professional environments. However, despite these strengths, there remains a notable gap between principle and implementation. While accreditation criteria acknowledge inclusivity, there is limited evidence of structured mechanisms to ensure universal accessibility or to accommodate diverse learning needs in practice. This suggests that while the foundation for inclusivity is present, further refinement is required to translate these principles into tangible, system-wide strategies that actively support all learners.

The findings of this study thus demonstrate progress in embedding holistic and human-centric principles through the EIAC and SARs, but the absence of explicit guidance on universal accessibility, diverse learning pathways, and structured strategies for inclusivity remains a limitation. This aligns with Lantada's (2020) position which emphasises the integration of ethical responsibility, inclusivity, and social awareness as fundamental to Engineering Education 5.0. In particular, the study’s identification of PO5 (Ethics and Professional Responsibilities) and PO3 (Design) as central to embedding human-centric values mirrors Lantada’s argument that engineering education must extend beyond technical expertise to incorporate ethical reasoning and sustainability principles.

In summary, holistic and human-centric principles are clearly articulated within accreditation frameworks and institutional practice, particularly through the integration of ethics, design, and teamwork outcomes. These elements ensure that graduates are encouraged to balance technical competence with societal awareness, ethical responsibility, and interpersonal skills. However, the findings also reveal persistent gaps. While inclusivity and accessibility are acknowledged, they are not consistently supported by structured strategies or system-wide mechanisms. Similarly, although leadership and management skills are increasingly embedded, the translation of human-centric ideals into universal practice remains partial. This highlights a tension between the recognition of holistic values in principle and the unevenness of their implementation across programmes.

5.3.7.1 Contextualising the findings within the existing literature

The findings align with broader debates about the need for engineering education to integrate human-centric values more systematically. While inclusivity and accessibility are increasingly acknowledged, they often remain implicit principles rather than fully embedded practices. Lantada (2020), Ghani (2022), and Mourtzis, Angelopoulos and Panopoulos (2023) argue that technological innovations and smart learning ecosystems could help bridge the gap between inclusivity ideals and their practical implementation, yet this potential has not been fully realised in the Irish accreditation context. The study's finding of a disconnect between accreditation criteria and their application resonates with Gürdür Broo, Kaynak and Sait's (2022) argument that Industry 5.0 demands education models that move beyond technical mastery to equip graduates for complex societal challenges.

Recent work strengthens these claims. Kovari (2024) highlights that human-centricity in Industry 5.0 education requires embedding inclusivity, emotional intelligence, and transdisciplinarity as core pedagogical principles, not as ancillary goals. Luna, Chong and da-Silva-Ovando (2024) similarly, frame Education 5.0 as inseparable from human well-being, emphasising that equity, accessibility, and sustainability must underpin learning design. Complementing these perspectives, in the systematic review of Engineering Education 5.0 Caratozzolo *et al.* (2024) underline the centrality of integrating social and human skills with technical training, positioning empathy, leadership, and adaptability as necessary complements to technical competence. Together, this literature reinforces the study's conclusion: while holistic and human-centric values are visible within accreditation and curricula, more deliberate, system-wide strategies are needed to translate inclusivity and accessibility from principle into consistent practice.

5.3.8 Conclusion

Across the seven features of the Engineering Education 5.0 model, findings reveal that professional discourses, accreditation frameworks, and institutional practices co-produce what counts as valuable competence. Accreditation safeguards the technical fundamentals of mathematics, problem-solving, and design, while also embedding ethics, sustainability, and lifelong learning. However, these latter elements are unevenly integrated, often treated as add-ons rather than core organising principles. Human-centricity, inclusivity, and accessibility remain weakly embedded; sustainability is formally recognised but operationalised inconsistently; and global readiness is largely equated with compliance to international accords rather than the cultivation of cultural competence. Emerging technologies, including AI and advanced automation, are acknowledged but lack systematic integration, reflecting accreditation's tendency to preserve continuity while being slow to embrace technological change. The analysis across the seven features of the Engineering Education 5.0 model thus reveals that accreditation in the HEI positions Industry 5.0 as a hybrid formation: anchored in safeguarding foundational technical knowledge, while selectively incorporating elements of sustainability, ethics, and human-centricity.

The analysis across the seven features of the Engineering Education 5.0 model indicates that accreditation positions Industry 5.0 as a hybrid formation: anchored in safeguarding foundational technical knowledge, while selectively incorporating elements of sustainability, ethics, and human-centricity.

This produces a version of Industry 5.0 that emphasises continuity with established engineering practices, rather than a radical break with them. For example, while accreditation explicitly codifies sustainability (through PA7) and ethics (through PO5), these are unevenly integrated across other outcomes, positioning them as add-ons rather than core organising principles. Similarly, collaboration and global perspectives are framed primarily in terms of teamwork and compliance with international accords, echoing Lantada's (2020) observation that international frameworks tend to prioritise standardisation over cultural adaptability. In this way, accreditation constructs Industry 5.0 as an incremental extension of existing frameworks rather than a transformative shift (Froyd, Wankat and Smith, 2012).

This tendency is particularly evident in the treatment of technical competencies, which are consistently prioritised across accreditation criteria and SARs, ensuring graduates acquire a strong foundation in mathematics, problem-solving, and design. Interviewees confirmed that these fundamentals are vital to professional formation. However, across the dataset, there is limited evidence of structured integration of emerging technologies such as AI, machine learning, or advanced automation, despite their perceived importance for future practice. Where data science appears, its treatment is fragmented, without a coherent progression across levels. As a result, Industry 5.0 is framed less as a human–machine partnership and more as a continuation of Industry 4.0, with a cautious nod towards digitalisation (Balart and Shryock, 2024; Supriya *et al.*, 2024). This aligns with international critiques that accreditation emphasises stability and is slow to respond to technological change. Studies in other contexts show the same lag: AI and human–machine collaboration are recognised as essential, but they remain largely absent from accreditation frameworks (Balart and Shryock, 2024; Pacher *et al.*, 2024; Supriya *et al.*, 2024; Koch *et al.*, 2025). This reflects a broader pattern of accreditation functioning as what Froyd, Wankat and Smith (2012) call a "protector of the status quo" (p.1345), privileging continuity while limiting responsiveness to Industry 5.0 imperatives.

Human-centricity and sustainability are acknowledged as central to the vision of Industry 5.0 (Breque, De Nul and Petridis, 2021) but were found to be often enacted in fragmented ways throughout the data. Human-centricity is enacted through ethics, teamwork, and lifelong learning, yet inclusivity and accessibility remain weakly embedded. Sustainability, meanwhile, is formally recognised but operationalised in fragmented ways across accreditation outcomes and institutional reporting. These findings echo Mazur and Walczyna's (2022) critique that sustainability is often presented as a technical challenge, and Byrne’s (2023) call for its recognition as a core principle. More recent studies reinforce this interpretation: Kovari (2024) highlights sustainability as a pedagogical pillar of Industry 5.0, while Galatro and Chakraborty (2025) demonstrate practical strategies for embedding circularity and life-cycle assessment vertically across curricula.

In terms of educational approach and collaboration, accreditation criteria were found to valorise lifelong learning and teamwork, but personalisation, inclusivity, and cross-disciplinary problem-solving remain peripheral. This positions Industry 5.0 as preparing adaptive yet standardised graduates, who are expected to continue learning but within relatively narrow institutional framings (Al-Emran and Al-Sharafi, 2022). This finding resonates with Sangwan and Venugopal’s (2022) argument that while students recognise the value of interdisciplinary collaboration, they often lack exposure to such contexts. Emerging work (Caratozzolo *et al.*, 2024; Golser *et al.*, 2025) further suggests that stakeholder engagement and interdisciplinary curricula are crucial for Industry 5.0, yet these dimensions remain peripheral in the accreditation processes examined in this study.

Global perspectives are most clearly articulated through alignment with Washington[17], Sydney[18], and Dublin Accords[19], ensuring graduate mobility and comparability of qualifications. However, cultural competence and global problem-solving are not explicitly addressed, reflecting a tendency to equate global readiness with regulatory compliance. This pattern resonates with critiques that global accreditation reinforces standardisation while overlooking relational and cultural dimensions of professional practice (Lantada, 2020; Luna, Chong and da-Silva-Ovando, 2024; Koch *et al.*, 2025).

Taken together, these findings demonstrate that analysis of the accreditation process in the HEI through the lens of the Engineering Education 5.0 model constructs Industry 5.0 less as a radical transformation and more as an incremental extension of existing practices. It produces a selective and negotiated version of Industry 5.0: progressive in recognising ethics, sustainability, and lifelong learning, but conservative in its treatment of emerging technologies, personalisation, and global cultural adaptability. In this way, accreditation can be seen to act as both a guarantor of stability and a limited driver of innovation, reinforcing its role as a negotiated policy practice that balances tradition and change, global alignment and local practice. Industry 5.0 in this context is therefore best understood as a hybrid formation, shaped through the interplay of discourses, institutional priorities, and accreditation practices. This analysis aligns with broader literature identifying accreditation as a negotiated policy practice that balances legitimacy, institutional

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[17] https://www.internationalengineeringalliance.org/accords/washington-accord

[18] https://www.internationalengineeringalliance.org/accords/sydney

[19] https://www.internationalengineeringalliance.org/accords/dublin

capacity, and international recognition against pressures for change (Martin, Conlon and Bowe, 2021; Gürdür Broo, Kaynak and Sait, 2022).

Having analysed the insights gained from the findings of this study and examined these results in the context of the most recent body of academic studies and publications in the field, attention is reverted to the Engineering Education 5.0 model developed and used in the study to explore how Industry 5.0 is constructed in engineering programmes. The following section reflects on the Engineering Education 5.0 model, critically examining its value and limitations as an analytical framework for this study.

5.4 Reflections on the Engineering Education 5.0 model

At the conclusion of the study, it is necessary to evaluate the usefulness of the Engineering Education 5.0 model in light of the emergent findings and discussion. Accordingly, this section (i) reviews how the model operated as the analytical lens for answering the research question and (ii) considers the model's continued utility and any updates suggested by the findings and newer literature.

5.4.1 Usefulness of the Model in the Context of the Study

The study offers promising evidence of the usefulness of the Engineering Education 5.0 model in accreditation practices within engineering programmes in an Irish HEI. By drawing attention to the specific features of Industry 5.0, it provided a structured yet flexible lens through which certain accreditation practices could be interrogated.

From a social constructionist perspective, the utility of the model lay in its ability to illuminate how accreditation does not merely identify Industry 5.0 readiness but actively participates in shaping what Industry 5.0 comes to mean in this context. For instance, examining accreditation texts through the lens of "sustainability" and "ethics and social impact" revealed not only whether these concepts were included but also how they were framed. Sustainability was cast as a technical systems concern, and ethics largely as compliance, demonstrating that accreditation constructs these categories in partial and particular ways. Similarly, the model's feature of "holistic and human-centricity" helped reveal the silences around inclusivity and accessibility, making visible the selective embedding of human-centred ideals within accreditation.

The Engineering Education 5.0 model also facilitated the comparison of accreditation practices across the three contexts of influence, text production, and practice identified in Ball's (1993) policy cycle framework. By drawing attention to interview insights, accreditation criteria, and SAR narratives, the model helped trace how particular features, such as technical competency or collaboration, were differently enacted across contexts. In this way, the study underscored that accreditation is not a neutral mechanism but a negotiated arena in which understandings of Engineering Education 5.0 are actively shaped and constructed.

At the same time, the use of the Engineering Education 5.0 model in its current form within this study revealed several limitations. First, by structuring the analysis around seven predefined features, the model risked constraining the interpretive lens, potentially privileging what was already conceptualised while obscuring emergent or cross-cutting themes. This was most evident where features such as sustainability and ethics were found to overlap, creating analytic difficulty in coding and interpretation. Second, the model's framing may have encouraged a degree of reification, as if Industry 5.0 could be captured through a bounded set of categories, when the findings suggest it is more accurately understood as a fluid and contested construct negotiated through accreditation practices. Third, the model had limited sensitivity to institutional and political dynamics beyond the programme level. For example, questions of funding, resources, or broader socio-economic pressures influencing accreditation were not foregrounded, even though they shape how Industry 5.0 is enacted. Thus, while the model proved effective as a heuristic scaffold, its application also underscored the need for reflexivity about the limits of categorical frameworks. From a social constructionist perspective, these limitations are instructive rather than fatal: they highlight that the Engineering Education 5.0 model itself is a constructed lens, one that inevitably shapes what is seen and what remains peripheral. Recognising these constraints strengthens rather than weakens the study, as it demonstrates the need for ongoing critical engagement with the model alongside empirical findings and emerging literature

5.4.2 Refining the Engineering Education 5.0 model

The refinement of the Engineering Education 5.0 model was a structured process that brought the original seven-feature model into dialogue with (i) the empirical findings from this study and (ii) the most recent literature on Industry 5.0 and engineering education. Concretely, this involved three steps.

First, for each of the seven original features, the findings from Chapter Four were synthesised into summary tables (Table 5-2 to Table 5-8), which integrated evidence from interviews, the EIAC, and the SAR programme outcomes. This provided a picture of how each feature was actually constructed and operationalised through accreditation practices in the case-study HEI. Second, these findings were compared with the conceptualisation of each feature in the original Engineering Education 5.0 model presented in Chapter Two, and with the new body of literature identified in Table 5.1. For each feature, these questions were asked:

What aspects of the original feature are strongly supported by the data?

Where do the findings reveal gaps, tensions, or overlaps between features?

What new emphases or categories are suggested by recent scholarship that were not adequately captured in the original model?

Third, using this comparative analysis, explicit decisions were made to retain, split, rename, or extend features of the original model. Consistent with the social constructionist stance of this study, the aim was not to correct the model but to refine it as a more precise and analytically useful lens. The outcome of this process is a revised nine-feature model (Table 5.9), which preserves the strengths of the original framework while addressing the empirical and conceptual limitations.

The remainder of this section explains, in turn, how the combination of findings and recent literature led to the specific amendments for each feature.

5.4.2.1 Technical Competency becomes Technical Competency (refined) and AI Literacy and Technical Responsibility

In the original model, Technical competency encompassed both foundational engineering knowledge and engagement with emerging technologies (AI, robotics, and cyber-physical systems). The findings strongly confirmed the centrality of technical competency across all three data sources; the interviews, EIAC, and SARs consistently foregrounded core engineering fundamentals and the need to keep curricula technologically up to date (see Table 5-2). However, the analysis also showed that references to AI, automation, and data systems were often implicit, uneven, or framed in narrow technical terms rather than as a broader literacy and responsibility issue. Recent literature has reinforced this observation. Authors such as Balart and Shryock (2024), Vieira, (2024), and Koch *et al.* (2025) emphasise the integration of AI, robotics, and cyber-physical systems as defining elements of Engineering Education 5.0, while newer work stresses AI governance, generative tools, and algorithmic accountability as critical graduate competences (Ciolacu *et al.*, 2023; Supriya *et al.*, 2024). When read alongside the present study's findings, this suggested that the original single feature was focused too much on conceptual work. As a result, technical competency is retained but refined to focus on applied technological problem-solving grounded in engineering fundamentals and the integration of emerging technologies for practical application. The AI-related themes that had previously been subsumed within technical competency are now elevated into a distinct feature, *AI Literacy & Technical Responsibility*, which captures the implications of engaging with AI, data, and automation, including ethical, regulatory, and accountability dimensions. This split both reflects patterns in the data (where AI and automation were increasingly visible but under-theorised) and aligns the model with the trajectory of the recent literature.

5.4.2.2 Sustainability and Ethics & Social Impact become Sustainability and Ethics, Social Impact & Digital Ethics

In the original model, Sustainability and Ethics and social impact were presented as separate features. However, during analysis of the EIAC and SARs, these domains frequently appeared entangled within the same segments of text, making it difficult to allocate evidence cleanly to one feature or the other. This overlap was particularly evident in PO5 (Ethics and Professional Responsibility), where environmental responsibility, professional duty, and social consequences were often articulated as part of the broader responsibility discourse (see Table 5.3 and Table 5.4). In practice, the findings tended to treat sustainability and ethics as adjacent obligations rather than as conceptually distinct educational commitments. At the same time, the findings indicated that this shared "responsibility" discourse was internally differentiated, with sustainability and ethics being framed in notably different ways across the accreditation texts. Sustainability was most commonly framed in terms of environmental stewardship, resource efficiency, and life-cycle considerations in design and practice. By contrast, ethics was typically expressed through compliance-oriented language, including adherence to professional codes and generalised claims about "doing the right thing." Notably, there was limited engagement with broader social justice questions, such as equity as a design and decision-making concern. There was also only minimal attention to digital ethics, for example, how programmes prepare graduates to anticipate and govern the harms associated with data-driven and algorithmic systems. This absence matters because digital infrastructures and intelligent systems increasingly shape the ethical challenges facing engineers (Balart and Shryock, 2024).

Recent scholarship helps sharpen this distinction and exposes what is underdeveloped in the EIAC and the SARs. Work from Caratozzolo, Chans and Dominguez (2025), Golser *et al.*, (2025), and Luger *et al.*, (2025) positions sustainability as an ecological and systems concern, emphasising life-cycle analysis, circularity, and long-term design foresight. Whereas other contributions foreground ethical issues that arise specifically in digital contexts, including data justice, algorithmic transparency, accountability, and the societal impacts of digital infrastructures(Ciolacu *et al.*, 2024; Doss *et al.*, 2024; Supriya *et al.*, 2024). This body of research treats ethics not only as professional conduct but as the ethical governance of digital technologies, that is, ensuring that data-driven and AI-enabled systems are designed, deployed, and monitored in ways that are fair, explainable, privacy-respecting, and accountable.

Bringing the empirical findings and the literature into dialogue, the model is refined in two ways:

- Sustainability is more tightly defined as an ecological and systems-oriented feature, centred on design foresight, life-cycle thinking, and circular economy principles.
- Ethics & Social Impact is extended and renamed *Ethics, Social Impact & Digital Ethics* to make explicit the normative questions that were only weakly evidenced in the accreditation documents, particularly equity, justice, responsibility, and the ethical governance of digital technologies.

This refinement responds directly to the analytic difficulty encountered during coding, where sustainability and ethics language often overlapped. It also addresses a substantive finding: ethical considerations in the EIAC and SARs are present, but they are largely framed as compliance rather than socio-digital responsibility. The revised feature, therefore, both clarifies boundaries for analysis and strengthens the model's capacity to represent the environmental and socio-digital dimensions of responsibility of Engineering Education 5.0.

5.4.2.3 Collaboration becomes Transdisciplinary Collaboration

The original Collaboration feature captured teamwork, stakeholder engagement, and cross-functional working. The findings of this study confirmed its importance, particularly through the emphasis on group work, industry projects, and professional skills in the SARs and interview accounts. However, collaboration was often framed in relatively traditional terms, as student group work or industry partnerships rather than as the broader ecosystemic and cross-disciplinary collaboration envisaged in Engineering Education 5.0. Recent literature pointed toward a more expansive understanding. Studies such as Doss *et al.* (2024), Golser *et al.* (2025), and Koch *et al.* (2025) highlight the need for transdisciplinary collaboration that brings together engineers, social scientists, designers, communities, and policy actors around complex socio-technical problems. When compared with the study's empirical findings, it became clear that although the data showed collaboration as present, the original label risked underplaying this wider, ecosystemic dimension. In response, the feature is reframed as *Transdisciplinary Collaboration*. This amendment is grounded in the study's findings, which already show movement towards co-creation with external partners; it extends them in line with recent scholarship by explicitly signalling the collapse of disciplinary silos and the shift toward problem-based, ecosystem-level collaboration characteristic of Engineering Education 5.0.

5.4.2.4 Educational Approach becomes Educational Approach (including modularity and micro-credentialling)

The original Educational approach feature focused on adaptability, student-centred learning, and lifelong learning. The study findings strongly supported this emphasis. Interviews and SARs highlighted modular structures, opportunities for elective choice, and a clear commitment to lifelong learning and continuous professional development (see Table 5-6). However, the findings also revealed tensions: while flexibility was valued, the accreditation process could sometimes constrain curricular innovation. Recent literature adds another layer. Authors such as Pacher *et al.* (2024) and Arregi *et al.* (2025) describe structural changes in engineering curricula, including modularity, stackable credentials, micro-credentialing, and flexible learning pathways, as key responses to Industry 5.0. Although these developments were beginning to surface in the case-study HEI, they were not explicitly reflected in the original feature definition. The feature is therefore retained but expanded to *Educational Approach (including modularity and micro-credentialling)*. This explicitly links the empirical evidence of flexible provision and lifelong learning with a broader international trend towards more granular, stackable, and personalised educational structures, while remaining sensitive to the constraints posed by accreditation.

5.4.2.5 Global and Cultural Perspectives becomes Global and Cultural Perspectives (clarified emphasis)

In the original model, Global and cultural perspectives sought to capture awareness of global challenges, intercultural competence, and international mobility. The findings showed that global dimensions were present but often framed through alignment with international accords (for instance, Washington, Sydney, and Dublin Accords) and quality assurance regimes rather than as lived global engagement or cultural competence (see Table 5-7). Global readiness, in other words, tended to be equated with regulatory comparability.

Recent work challenges this narrow framing. Luna, Chong and da-Silva-Ovando (2024) and Koch *et al.* (2025) argue that Engineering Education 5.0 demands more than international alignment; it requires graduates who can navigate global, culturally diverse environments and address transnational challenges in contextually sensitive ways.

On this basis, *Global and Cultural Perspectives* is retained as a distinct feature, but its emphasis is clarified. In the refined model, it moves beyond regulatory alignment to highlight cultural sensitivity, global problem-solving, and engagement with diverse communities. This reframing is grounded in the observed gap between formal international alignment and the limited explicit attention to cultural competence in the case-study context.

5.4.2.6 Holistic and Human-Centricity becomes Holistic and Human-Centricity and Human Capabilities

The Holistic and human-centric feature played a pivotal role in the original model, bringing together ideas of well-being, inclusivity, and broader human-centric design principles. In practice, however, the findings showed that this feature was diffuse. Codes related to wellbeing, accessibility, inclusivity, and interpersonal skills appeared across multiple programme outcomes and often overlapped with ethics, sustainability, and educational approach (see Table 5-8). This made it difficult to sustain a clear analytic distinction. At the same time, the data confirmed that human-centric values were increasingly invoked in accreditation discourse, though their operationalisation remained uneven. Recent literature reinforces the centrality of human-centricity to Engineering Education 5.0 (Balart and Shryock, 2024; Ciolacu *et al.*, 2024), while other studies explicitly highlight human capabilities such as resilience, emotional intelligence, and tolerance for ambiguity as key graduate attributes (Caratozzolo *et al.*, 2024; Luna, Chong and da-Silva-Ovando, 2024). Bringing these strands together suggested that a single, broad feature was obscuring two analytically distinct dimensions:

- A system-level, value-oriented concern with designing technologies, organisations, and curricula around human flourishing (holistic and human-centric), and

- An individual-level focus on the interpersonal, affective, and psychological capacities that engineers need to navigate complex, uncertain environments (human capabilities).

The model is therefore refined by retaining *Holistic and Human-Centric* as a feature focused on the design and governance of systems with human wellbeing and social flourishing at their core and introducing a new feature, *Human Capabilities*, to explicitly capture attributes such as emotional intelligence, resilience, adaptability, and ambiguity tolerance. This distinction is directly informed by the empirical difficulty of locating these codes within a single category and by the literature's growing emphasis on affective and interpersonal dimensions as central, not peripheral, to Engineering Education 5.0.

5.4.2.7 The Updated Model of Engineering Education 5.0

A summary of the updated Engineering Education 5 .0 model is presented in Table 5.9. It shows feature-by-feature changes along with the supporting rationale.

Table 5-9: Feature refinement of the Engineering Education 5.0 model

Original Feature	Refined Feature	Rationale for Change from findings and recent literature
Technical Competency	Technical Competency and AI Literacy & Technical Responsibility	Need to explicitly recognise AI governance, automation literacy, and algorithmic accountability
Sustainability	Sustainability (Ecological Systems, Design Foresight)	Clarified as ecological systems thinking and design foresight, aligned with sustainability in practice
Ethics & Social Impact	Ethics, Social Impact & Digital Ethics	Expanded to incorporate digital ethics, data justice, algorithmic transparency, and participatory governance
Collaboration	Transdisciplinary Collaboration	Shift from teamwork to transdisciplinarity, reflecting dissolution of disciplinary silos and ecosystemic approaches
Educational Approach	Educational Approach (Lifelong learning and Modularity & Microcredential delivery)	Beyond adaptability, now includes modularity, stackability, and microcredentialing for flexible curriculum design
Global & Cultural Perspectives	Global & Cultural Perspectives	Still relevant but needs stronger operationalisation to move beyond regulatory compliance and foster global cultural adaptability
Holistic & Human-Centricity	Holistic & Human-Centricity and Human Capabilities	Separated human capabilities from broader human-centric framing to give them clearer visibility

The move from seven to nine features arises directly from a systematic comparison of the original Engineering Education 5.0 model with the integrated findings of this study and the latest international literature. The core logic of the amendments can be summarised as follows:

- Where the data and literature indicated distinct conceptual domains, overloaded features were divided. For instance, *Technical Competency* is separated into *Technical Competency* plus *AI Literacy and Technical Responsibility*, while *Holistic and Human-centricity* is divided into *Holistic and Human-centricity* plus *Human Capabilities*.
- Overlapping features were clarified by refining conceptual boundaries. For example, distinguishing *Sustainability* from *Ethics, Social Impact, and Digital Ethics*.
- Other features were reframed and extended to better capture ecosystemic and structural shifts identified in the findings and recent scholarship. For example, *Transdisciplinary Collaboration* and *Educational Approaches* incorporating modularity and micro-credentialing.

The need to revise the original seven-feature model is not merely a methodological reflection but an empirical and conceptual outcome of the study. The integrated findings, together with post-2023 scholarship, indicate that the original model did not fully capture several structural shifts now shaping engineering education, particularly the increasing centrality of data-driven technologies, modular and flexible learning approaches, and expanding expectations of graduate capability beyond technical proficiency alone. The revised model addresses these shortcomings by refining conceptual boundaries and incorporating the emerging domains that are increasingly consequential but were not adequately captured in the original framework. The updates have led to the development of a model that is both more coherent and better aligned with the realities currently shaping engineering education. This includes the impact of accreditation criteria, institutional constraints, and the increasing expectations of graduate responsibilities in the context of Industry 5.0.

In practical terms, the revised nine-feature model makes explicit what was previously compressed or implicit. This includes the rising centrality of digital and AI-related responsibility as sociotechnical systems proliferate. It also reflects the growing importance of human capabilities alongside technical competence in human-centric settings, as well as the structural reconfiguration of learning through modularity and flexible pathways that extend existing models of lifelong learning.

Thus, taken together, the updated features identified through this reflective analysis provide a more nuanced and analytically robust model of Engineering Education 5.0, grounded in the empirical realities of Irish accreditation practice and aligned with emerging international conceptions of Industry 5.0 as sustainability-oriented, human-centric, and responsibility-intensive. The updated model is presented in Table 5-10.

Table 5-10: Features and focus of the refined Engineering Education 5.0 model

	Feature	Focus
1	Technical Competency	Applied technological problem-solving - mastery of engineering fundamentals and integration of emerging technologies (AI, robotics, data systems) for practical application
2	AI Literacy and Tech Responsibility	Implications of engagement with AI - understanding AI's societal impacts, digital ethics, data sovereignty, and responsible innovation practices
3	Sustainability	Environmental systems thinking - focus on life-cycle design, resource efficiency, and ecological resilience in engineering decisions.
4	Ethics, Social Impact and Digital Ethics	Normative and value-based reasoning - critical reflection on equity, justice, and social consequences of engineering practices and innovations.
5	Transdisciplinary Collaboration	Working across knowledge and sectoral boundaries - engagement in collaborative, ecosystem-level problem-solving beyond traditional disciplinary silos
6	Educational Approach	Personalised and flexible learning - emphasis on modular, stackable, and lifelong learning structures that support learner autonomy and adaptability
7	Global and Cultural Perspectives	Intercultural competence and global-local awareness - ability to navigate global challenges while remaining responsive to cultural contexts and regional needs
8	Holistic and Human-Centricity	Empathy and human-focused design - integration of emotional intelligence, well-being, and user-centred principles into technology development
9	Human Capabilities	Emotional and adaptive intelligence - development tolerance, and leadership for complex and uncertain contexts

Beyond offering a refined conceptual map, the updated model provides a structured framework for evaluating how accreditation criteria support Engineering Education 5.0 in practice. It enables areas of strength to be distinguished from areas that are emerging, weakly specified, or under-assessed. In this sense, the model can function as both a diagnostic and evaluative tool, informing curriculum design, accreditation preparation, and policy discussion by making visible patterns of emphasis, omission, and tension across accreditation texts and institutional enactment. It is also noted that, consistent with the original Engineering Education 5.0 model, resilience remains embedded within the updated framework as a cross-cutting quality, reflected in expectations of adaptability, lifelong learning, and programmes' capacity to respond to technological and societal change

Finally, only after establishing the model's contribution in these terms does its constructionist implication become central: the Engineering Education 5.0 model should be understood as robust but revisable, shaped through ongoing interaction between accreditation standards, institutional interpretation, and evolving scholarly and societal expectations. Its value lies in its capacity to support clearer judgment and dialogue about what engineering programmes are being asked to produce in the era of Industry 5.0.

5.5 Conclusion

The Engineering Education 5.0 model was developed as a heuristic to explore how Industry 5.0 is constructed engineering programmes. Using the model as an analytical lens, findings from this study reveal significant strengths as well as gaps in the professional accreditation of engineering programmes in a HEI in Ireland in preparing engineering graduates for Industry 5.0.

This chapter has shown that through the lens of the Engineering Education 5.0 model, accreditation both reflects and actively constructs Industry 5.0 in the HEI in Ireland. Through this lens, accreditation practices emerge as selective framings that safeguard traditional competencies while cautiously incorporating and developing imperatives such as sustainability, ethics, and human-centricity. Yet these incorporations were found to be partial and uneven, revealing tensions between continuity and transformation, compliance and innovation, global alignment and local enactment.

In light of the study's findings, combined with an awareness and incorporation of more recent scholarly works, the chapter presents a revised nine-feature Engineering Education 5.0 model, which makes explicit several areas that were previously compressed or implicit, including AI literacy, digital ethics, human capabilities, and transdisciplinary collaboration, alongside a sharper distinction between sustainability and ethics and social impact.

Building on this recognition, the final chapter turns to conclusions and recommendations, considering how the insights gained here might inform both future accreditation practices and the ongoing development of the Engineering Education 5.0 model within the wider landscape of Industry 5.0.

Chapter 6: Conclusion

6.1 Introduction

This thesis has examined how Industry 5.0, through the lens of Engineering Education 5.0, is constructed through accreditation practices in engineering programmes in a HEI in Ireland. The study was motivated by the recognition that although accreditation is central to defining the quality and character of engineering programmes, its role in shaping responses to Engineering Education 5.0 had not been critically explored. It is believed that the insights gained from this study will illuminate how professional accreditation can operate as a dynamic site where Engineering Education 5.0 is discursively constructed, institutionally enacted, and translated into the evolving identity of engineering education in Ireland.

This final chapter restates the research questions and outlines the study's approach before synthesising the core findings across the three contexts of influence, text production, and practice, highlighting key areas of alignment and tension in the construction of Engineering Education 5.0. It then presents the study's main contributions, acknowledges its limitations, and offers recommendations for policy, practice, and future research. The chapter concludes by drawing together the conceptual, methodological, and empirical insights of the thesis and reflecting on the researcher's professional learning.

6.2 Research questions and approach to research

This study set out to examine how Industry 5.0 is constructed through accreditation practices in engineering programmes within an Irish Higher Education Institution (HEI). The overarching research question guiding the inquiry was:

> **Through the lens of Engineering Education 5.0, how does accreditation in engineering programmes at a Higher Education Institution in Ireland prepare students for Industry 5.0?**

To explore this question in depth, three sub-questions were developed to address the multiple layers of the accreditation criteria development and deployment process:

1. *Through the lens of Engineering Education 5.0, how do members of the accreditation board of Engineers Ireland understand the current accreditation criteria?*
2. *How is Engineering Education 5.0 represented in the 2021 Engineers Ireland Accreditation Criteria?*
3. *How is Engineering Education 5.0 represented in the programme outcomes in the self-assessment reports produced as part of accreditation in a HEI in Ireland?*

These questions were designed to capture how the concept of **Engineering Education** 5.0 is negotiated across different policy contexts.

The study adopted a social constructionist orientation, viewing knowledge as co-constructed through discourse, interaction, and institutional practice, and employed a qualitative, exploratory case study design consistent with this approach. This approach enabled an in-depth exploration of how accreditation operates as a dynamic site where meanings about Industry 5.0 in engineering education are constructed, negotiated, and enacted. Guided by Ball's (1993) policy cycle framework, which offered a means of tracing how policy texts are shaped through interrelated contexts of influence, text production, and practice, data were generated from three complementary sources:

- Semi-structured interviews with members of the Engineers Ireland Accreditation Board, representing the context of influence, provided insight into how **Engineering Education** 5.0 priorities are interpreted and negotiated by key stakeholders.
- The 2021 EIAC, representing the context of text production, were analysed to examine how **Engineering Education** 5.0 principles are codified within official accreditation policy.
- SARs produced by an HEI undergoing accreditation, representing the context of practice, were examined to understand how these discourses are enacted and operationalised within institutional settings.

The analysis was guided by Ball's (1993) policy cycle framework, which offered a means of tracing how policy texts are shaped through interrelated contexts of influence, text production, and practice. This was complemented by Braun and Clarke's (2019) reflexive thematic analysis (RTA), which supported an interpretive and iterative process of coding and theme development, consistent with the study's social constructionist stance.

To provide a structured analytical lens, the study developed and employed the Engineering Education 5.0 model, synthesised from existing literature and verified through empirical engagement. This model comprises features: technical competency, sustainability, ethics and social impact, collaboration, educational approach, global and cultural perspectives, and holistic human-centricity. It functioned as a heuristic tool that enabled systematic interrogation of how accreditation discourses and practices collectively construct the meaning of Industry 5.0 within Irish engineering education.

6.3 Summary of findings

This study examined how Industry 5.0, through the lens of Engineering Education 5.0, is constructed through accreditation practices in engineering education within an Irish HEI. Drawing together findings from interviews, the EIAC, and institutional SARs, this approach enabled an in-depth exploration of how accreditation operates as a dynamic process through which meanings of Industry 5.0 are constructed, negotiated, and enacted within engineering education.

The findings reveal that in a HEI in Ireland, through the lens of Engineering Education 5.0, accreditation simultaneously enables and constrains the embedding of Industry 5.0.

Within a social constructionist frame, the study shows how concepts such as ‘quality’, ‘accreditation’, and ‘readiness for Industry 5.0’ are socially produced, interpreted, and enacted across professional, regulatory, and institutional contexts.

At the context of influence, accreditation board members conceptualised Industry 5.0 as an evolving paradigm that should inform but not dominate accreditation criteria. Their interpretations reflected both commitment to core engineering values and recognition of the need to incorporate, for instance, sustainability, ethics, and human-centric design more explicitly.

At the context of text production, the 2021 EIAC codified many of these aspirations, embedding sustainability and ethics within the accreditation framework. However, the analysis also revealed selective emphasis: while traditional domains such as technical competence, ethics, and professional responsibility were well-defined, areas central to Industry 5.0 and the related features of Engineering Education 5.0, such as global awareness, lifelong learning, and human-centricity, were unevenly articulated and often treated as peripheral themes.

At the context of practice, the POs in the SARs showed that the HEI interprets and enacts accreditation guidance through a localised lens. Programmes demonstrated strong alignment with established competencies, particularly technical and ethical standards, but exhibited varying depth in integrating sustainability, digital innovation, and intercultural perspectives.

Across all three contexts, technical competence and ethics emerged as stabilised and dominant domains, reflecting continuity with established professional norms. In contrast, sustainability, global outlook, and human-centricity were inconsistently embedded, often positioned as desirable rather than essential outcomes. Emerging priorities, such as AI literacy, modular and personalised learning, and intercultural competence, received limited systematic attention despite their increasing prominence in international discourse. These gaps underscore a persistent tension between maintaining traditional benchmarks of professional identity and responding to the transformative imperatives of the drivers of Industry 5.0.Drawing the findings together, when viewed through the Engineering Education 5.0 lens, accreditation prepares students for Industry 5.0 by stabilising and legitimising what counts as graduate competence and then translating those priorities within the HEI. Across Ball’s (1993) contexts, the study shows a clear baseline strength: accreditation safeguards core technical skill formation and professional standards, while also incorporating Industry 5.0 relevant priorities, most notably sustainability, ethics, lifelong learning, and teamwork, into the Engineers Ireland accreditation criteria, and the evidence contained in the self-assessment reports. However, this preparation is selective and uneven. Sustainability and ethics are often framed in compliance and technical terms, human-centricity remains weakly tied to inclusivity and accessibility, and emerging Industry 5.0 capabilities, such as, AI literacy, socio-digital governance, and transdisciplinary problem-solving are not yet consistently specified or assessed. As a result, accreditation constructs Industry 5.0 readiness less as a transformational shift and more as a negotiated, hybrid extension of established professional norms. This enables movement toward Industry 5.0 while simultaneously constraining how far and how fast that movement can occur through accreditation alone.

6.4 Contributions of this research study to knowledge and practice

This study makes contributions to engineering education research, engineering education in Ireland, and the researcher's professional practice. It demonstrates how accreditation, far from being a static or technical process, is a socially constructed policy mechanism, shaped by competing interpretations, contextual practices, and institutional negotiations.

6.4.1 Engineering education research

6.4.1.1 The Engineering Education 5.0 model.

A central contribution of this research is the development of the Engineering Education 5.0 model as an analytical framework that makes visible and assessable how accreditation prepares students for Industry 5.0 in practice. The model advances engineering education research by providing a structured yet adaptable heuristic that captures how features central to Industry 5.0, such as sustainability, ethics, collaboration, and human-centricity, are discursively produced and negotiated through policy and institutional processes. Rather than prescribing what engineering education should look like, the model reveals how accreditation actively shapes, privileges, or marginalises particular understandings of Industry 5.0 through the features of Engineering Education 5.0.

The model builds upon and extends prior scholarship by moving beyond conceptual discussions of what Engineering Education 5.0 should entail (Lantada, 2020) or strategic calls for preparing education systems for Industry 5.0 (Gürdür Broo, Kaynak and Sait, 2022). A key contribution is that it offers institutions a practical framework for examining how the features of Engineering Education 5.0 are operationalised, adapted, and contested, thereby bridging the gap between theoretical ambition and institutional reality (Ghani, 2022).

As shown in Chapter Five, the model also contributes new insight into the ways accreditation practices construct Industry 5.0, exposing both the interpretive flexibility and the selective emphasis of accreditation criteria. Its strength lies in enabling a discursive analysis that reveals how values such as human-centricity or sustainability are differently articulated across contexts of influence, text production, and practice. From a social constructionist perspective, this interpretive capacity is a key contribution: the model demonstrates how meaning-making within accreditation can be empirically examined rather than assumed, offering a novel methodological bridge between policy analysis and engineering education research.

The contribution of the model is further evidenced by its capacity for evolution. Through its application in this study, the model was refined from seven to nine interrelated features, reflecting the dynamic and expanding scope of Engineering Education 5.0 in response to emerging

Industry 5.0 imperatives. This evolution integrates emerging concerns identified in current literature, including AI literacy and algorithmic accountability (Ciolacu *et al.*, 2024; Supriya *et al.*, 2024), the differentiation of sustainability from ethics and digital responsibility (Doss *et al.*, 2024; Golser *et al.*, 2025), and the reframing of collaboration as transdisciplinary and ecosystemic (Caratozzolo, Chans and Dominguez, 2025; Koch *et al.*, 2025). This responsiveness illustrates that the model's utility lies not in being a static taxonomy but in being a discursive construct that evolves in dialogue with emerging practice and scholarship, offering a tool for future research examining how Engineering Education 5.0 is embedded within programmes. Thereby it will remain fit-for-purpose as a framework for evaluating how engineering education is being aligned with Industry 5.0.

6.4.1.2 Reframing accreditation through policy analysis

A methodological contribution of this research is the reframing of accreditation as a policy process through the integration of Ball's (1993) policy cycle framework within a qualitative, social constructionist approach**.** This study demonstrates that policy analysis is not confined to legislative or governmental contexts but can be effectively applied to professional accreditation to reveal how criteria are constructed, negotiated, and enacted**.** By positioning accreditation as a policy artefact, the research moves beyond compliance-oriented studies that treat criteria as static benchmarks (Conlon, Nicolaou and Bowe, 2017). Instead, it shows how meaning is actively co-produced by actors across institutional and professional domains.

Through the triangulation of interviews, EIAC, and SARs**,** the study illustrates how, through the lens of Education Engineering 5.0, different stakeholders interpret and operationalise Industry 5.0 priorities within the accreditation process. This application of policy analysis exposes the discursive and contextual nature of accreditation, revealing how national frameworks, institutional cultures, and professional norms converge to shape what counts as quality and competence in engineering education.

This methodological integration makes a distinct contribution to engineering education research by demonstrating the value of qualitative and reflexive policy analysis in capturing the fluid, contested, and interpretive dimensions of accreditation practice (Martin, Conlon and Bowe, 2021; Murphy, Christensen and Conlon, 2022). It positions policy analysis as a tool for understanding how emerging paradigms, such as Industry 5.0, are translated from discourse into institutional reality, and in doing so, expands the methodological repertoire available for studying engineering education systems.

Together, these contributions to engineering education research - the Engineering Education 5.0 model and the application of policy analysis as a qualitative methodological lens, provide a foundation for examining how the specific dynamics of engineering education in Ireland shape the enactment of Industry 5.0 through accreditation practices.

6.4.2 Engineering education in Ireland

This study makes a contribution to debates about the future of engineering education in Ireland, where accreditation remains the central mechanism through which professional identity, quality, and competence are defined. From a social constructionist perspective, the research demonstrates that accreditation is co-produced through dialogue and negotiation among Engineers Ireland, HEIs, and industry stakeholders. By revealing how these negotiations stabilise and contest meanings of Industry 5.0, the study contributes to Irish policy and practice in the following ways:

- Situating accreditation as negotiated policy -This study positions accreditation as a negotiated and enacted policy process rather than a fixed standard. Using Ball's (1993) policy cycle framework, it shows how accreditation criteria were interpreted, produced, and enacted within the case-study institution. For example, sustainability was framed as a technical concern in one SAR and as a strategic institutional priority in another. These findings offer indicative evidence that, within this context, accreditation functions as a socially situated form of policymaking, extending the work of Conlon, Nicolaou and Bowe (2017) by illustrating how policy enactment can occur through accreditation practice.
- Advancing curriculum innovation as a socially situated process - Through the development of the Engineering Education 5.0 model, this study contributes a structured analytical framework that HEIs can use to examine and strengthen their curricula. This contribution is especially relevant to Industry 5.0, as it offers HEIs a way to translate its human-centric, sustainability and resilience imperatives into programme priorities that can be evidenced, assessed, and defended within accreditation processes. By mapping accreditation criteria against the model, the research demonstrates how curricular priorities such as sustainability as ecological foresight (Caratozzolo, Chans and Dominguez, 2025), ethics as social responsibility and digital justice (Supriya et al., 2024), and collaboration as transdisciplinary engagement (Koch *et al.*, 2025) can be more systematically conceptualised. These insights suggest that efforts to innovate curricula are influenced by local institutional contexts, priorities, resources, and pedagogical cultures, indicating that curriculum development is negotiated through practice rather than determined solely by compliance with external standards.
- Extending the conceptual scope of accreditation - The findings contribute to the Irish engineering education discourse by questioning the assumption that accreditation should remain narrowly focused primarily on technical competencies. While the study found that accreditation currently prioritises these areas, the synthesis of findings with recent literature highlights the growing relevance of emergent discourses such as AI literacy, modular learning, and global engagement (Ciolacu *et al.*, 2024; Arregi *et al.*, 2025). These developments point to the expanding expectations of what it means to be an Industry 5.0-ready engineer. In this context, the study offers a basis for Engineers Ireland to reflect on

how future accreditation frameworks might evolve to incorporate micro-credentials, adaptive learning pathways, and transdisciplinary integration. This contribution, therefore, positions accreditation as a dynamic framework that can adapt to ongoing societal and technological change.

- Repositioning Ireland's engineering education identity - The research contributes to Ireland's strategic positioning within global engineering education by demonstrating how accreditation discourses shape the country's professional and cultural reputation. It shows that by embedding global competence, inclusivity, and human-centricity within accreditation frameworks, Ireland can enhance its leadership in Industry 5.0 focused education (Luna, Chong and da-Silva-Ovando, 2024; Golser *et al.*, 2025). Conversely, neglecting these features risks reinforcing outdated paradigms and diminishing Ireland's global standing.

Taken together, these contributions show that accreditation in Ireland is a contested yet continuously evolving construct through which the future of engineering education is negotiated. The findings provide both empirical evidence and a conceptual framework for dialogue among Engineers Ireland, HEIs, and industry, positioning accreditation as a dynamic process of constructing educational futures responsive to societal, technological, and global change.

6.4.3 Researcher's professional practice

This final section turns inward to consider the researcher's professional practice. This part highlights how the process of conducting this research has generated new professional insights, reflexive learning, and pedagogical approaches within engineering education.

- Curriculum design and reflective practice - Through the use of the Engineering Education 5.0 model, the researcher was able to critically evaluate how her modules align with Industry 5.0 competencies. This revealed how established framings, for instance, sustainability as a technical systems issue or ethics as compliance, often overshadow broader social or human-centric dimensions. Recognising these silences encouraged the researcher to adapt teaching approaches and assessment strategies, seeking to construct learning environments that are more inclusive, dialogical, and globally responsive.
- Accreditation engagement - During recent accreditation processes, the findings of this study enabled the researcher to contribute an evidence-based critique of graduate attributes. Rather than treating outcomes as fixed categories, the researcher advocated for understanding them as evolving constructs negotiated through dialogue with industry and society. This perspective reframed institutional discussions from a compliance-driven focus toward a more reflexive engagement with how accreditation discursively produces Industry 5.0.

- Pedagogical innovation - The research also influenced the researcher's adoption of new pedagogical practices. Greater emphasis has been placed on adaptive and personalised learning pathways, inclusive assessments, and encouraging students as co-constructors of knowledge. These practices align with international debates on modularity, stackability, and micro-credentialing (Pacher *et al*., 2024; Arregi *et al*., 2025).
- Policy engagement - At the national level, the study strengthened the researcher's contributions to policy discussions on accreditation reform. Identifying gaps in areas such as sustainability, global outlook, and AI literacy, the research provides a basis for challenging the assumption that accreditation frameworks can remain static. Instead, it positions accreditation as a reflexive and evolving construct that must respond to shifting industrial, societal, and technological demands.
- Research identity and methodological practice - Finally, the qualitative and interpretive orientation of this study has influenced the researcher's professional identity. By demonstrating the value of capturing lived experiences and contextual narratives, the study highlights accreditation and Industry 5.0 as socially constructed phenomena. This orientation strengthens professional practice by foregrounding reflexivity, negotiation, and responsiveness in both teaching and policy engagement, which will inform future scholarship.

6.5 Limitation of the study

This study examines how accreditation practices within one Irish higher education context engage with Industry 5.0 imperatives, but several limitations affect the scope and generalisability of the findings:

- Contextual scope - The study was limited to a single HEI and focused on Engineers Ireland's accreditation framework. While offering depth, this narrow focus means that findings may not be transferable to other national systems or institutional contexts.
- Focus on accreditation - Although accreditation was the central focus, other influential forces shaping curricula, such as institutional strategies or industry-driven training, were not systematically examined. As a result, the study presents a partial view of engineering education reform.
- Methodological constraints - The qualitative, social constructionist approach prioritised participant perspectives and contextual understanding rather than generalisable conclusions. Insights are based on interpretive analysis of stakeholder interviews, documents, and policies, and should be understood as situated rather than definitive.
- Lack of graduate follow-up - The study did not include data on graduates' career trajectories or perceptions, limiting its ability to assess the real-world impact of accreditation on employability or professional development.

- Limited stakeholder representation - While input from a HEI and policy actors was included, perspectives from students, graduates, and industry employers were underrepresented. This limits the study's capacity to evaluate the full stakeholder ecosystem of engineering education.
- Conceptual framing of Industry 5.0 - The Engineering Education 5.0 model did not include resilience as a standalone feature, instead treating it as a cross-cutting quality embedded within educational approaches, sustainability, collaboration, and holistic and human-centric practice. While this is consistent with the study's constructionist stance, it may have under-emphasised or obscured specific dimensions of resilience, for instance, infrastructural, organisational, or socio-technical, limiting the precision with which accreditation's engagement with this pillar of Industry 5.0 could be examined.
- Evolving paradigm - Industry 5.0 is a rapidly emerging field. Accreditation systems, by contrast, evolve more slowly. Therefore, findings and recommendations may require periodic revisiting as new developments unfold.
- Focus on programme outcomes of SARs only - The analysis of SARs was confined to their programme outcomes sections, which limited the exploration of how accreditation evidence is assembled, validated, and interpreted within the broader process. Other components, such as the supporting documentation submitted by the HEI or the perspectives of students and graduates, were not examined. As a result, the study captures how Industry 5.0 is represented in formal programme documentation but not how it is experienced or evidenced across the full accreditation process.

These limitations were partially mitigated by the study's theoretical grounding and triangulation of data sources. Nonetheless, they should be considered when interpreting findings or applying recommendations beyond the immediate research setting.

6.6 Recommendations

6.6.1 Policy level recommendations for Engineers Ireland

The study's findings indicate that while Engineers Ireland provides a robust framework, its approach could be more adaptive to Industry 5.0 realities. However, the study's scope did not include detailed policy evaluation or in-depth consultation with Engineers Ireland's wider stakeholders; thus, recommendations remain indicative rather than prescriptive.

- Align accreditation more explicitly with Industry 5.0 by making sustainability a standalone programme outcome - The current accreditation framework integrates sustainability primarily through PO5 (Ethics and Professional Responsibility) and PO3 (Design). However, findings from this study suggest that this indirect approach can lead to inconsistent or superficial treatment of sustainability across programmes. Engineers Ireland should consider establishing sustainability as a distinct programme outcome in the next iteration of the accreditation criteria. This would require programmes to explicitly demonstrate how students develop sustainability competencies. Elevating sustainability to a standalone programme outcome would signal its critical importance to Industry 5.0 and ensure a more consistent and measurable integration across accredited programmes.

- Encourage flexibility within accreditation - Engineers Ireland should clarify how HEIs can experiment with new pedagogies or modular formats, for instance, micro-credentials, without jeopardising compliance. This would help reconcile innovation with quality assurance, a tension noted in the findings.
- Explore alternative models of accreditation - While beyond the study's empirical scope, findings support further investigation into more dynamic accreditation models, such as those incorporating competency-based or portfolio-based assessments. Engineers Ireland should consider pilot initiatives in partnership with HEIs.
- International benchmarking - Given Ireland's growing global engagement, accreditation policies might benefit from comparative analysis with countries leading in Industry 5.0 transitions. The study noted that current frameworks are predominantly Western and may not fully address diverse global challenges.

These recommendations reflect opportunities for policy evolution in response to the contextual limitations and affordances identified in the study.

6.6.2 Practice level recommendations for HEIs and educators

This study highlights the importance of embedding Industry 5.0 competencies into engineering education. However, its scope was limited to one Irish HEI and the Irish accreditation framework. Therefore, the recommendations presented here are intentionally pragmatic and reflect the specific institutional and accreditation contexts studied.

- Incremental curricular innovation - Rather than large-scale curriculum redesign, HEIs should begin by incorporating interdisciplinary, human-centric content into existing modules through case studies, industry-informed projects, or sustainability challenges. This aligns with the study's finding that current programmes allow some discretion for localised innovation, even within the constraints of accreditation.
- Flexible learning opportunities - Personalised learning should be approached through manageable interventions, such as elective modules, digital learning supports, or project-based assessments that reflect student interests and Industry 5.0 themes. The study did not find comprehensive institutional strategies for personalisation, so pilot initiatives are a realistic starting point.
- Strengthened industry engagement - The study underscored the value of closer links between academia and industry. HEIs should build on existing relationships by expanding

placement schemes, inviting industry speakers, and co-designing final-year projects to align educational outcomes with workforce needs.

- Explicit integration of ethics and sustainability - While ethics and sustainability are part of accreditation, their implementation varies. HEIs should ensure that learning outcomes in these areas are explicitly assessed and that they cut across multiple modules rather than being siloed in standalone courses.
- Professional development support for educators - The study found that adaptation to Industry 5.0 requires pedagogical change. Institutions should invest in training for academic staff focused on digital tools, interdisciplinary teaching, and emerging ethical challenges in engineering.

These recommendations aim to support feasible enhancements rather than systemic reform and are grounded in the specific institutional dynamics observed.

6.6.3 Future research

The Engineering Education 5.0 model proposed in this study offers a conceptual foundation for aligning accreditation with Industry 5.0. However, this research was exploratory and context-specific, suggesting several avenues for further inquiry:

- Graduate outcomes studies - Longitudinal tracking of engineering graduates from accredited programmes would provide empirical evidence on whether accreditation criteria translate into career readiness in Industry 5.0 roles.
- International comparisons - Cross-national studies could compare accreditation frameworks to identify adaptable features from systems more advanced in Industry 5.0 implementation, such as in Japan or Germany.
- Institutional innovation within accreditation limits - Further research could examine how HEIs navigate accreditation constraints while experimenting with personalisation, interdisciplinarity, and new pedagogies.
- Stakeholder perspectives - Multi-stakeholder research involving students, employers, and alumni would enrich understanding of accreditation’s perceived effectiveness and gaps.
- Exploration of alternative accreditation models - Investigating micro-credentialing, stackable learning pathways, or competency-based accreditation frameworks could support more responsive and inclusive forms of recognition.

These future directions would help validate, extend, or refine the Engineering Education 5.0 model and its practical implications.

6.7 Conclusion

This study contributes to ongoing debates in engineering education by evidencing how professional accreditation mediates the incorporation of Industry 5.0 competencies into curricula. Accreditation emerges as a mechanism that frames, prioritises, and at times constrains educational innovation and not as a neutral arbiter. In doing so, it plays a central role in defining what counts as readiness for Industry 5.0.

The research has offered several contributions. Conceptually, it developed and refined the Engineering Education 5.0 model, demonstrating its value as a heuristic for analysing accreditation while recognising its provisional and evolving nature. Methodologically, it combined Ball's policy cycle with a qualitative, interpretive orientation, showing how policy texts, professional discourses, and institutional practices interact to construct educational meaning. Empirically, the study provided an in-depth account of how accreditation practices operate within one Irish HEI, illustrating areas of strong alignment (such as ethics and technical competence) and uneven integration (such as sustainability, inclusivity, and AI literacy) in relation to the wider accreditation framework.

The conclusions also carry implications for policy and practice. For Engineers Ireland, they highlight the need to reconsider whether current accreditation criteria sufficiently address emerging competencies especially around sustainability. For HEIs, they point to opportunities for curriculum innovation within accreditation frameworks. More broadly, they signal the importance of maintaining accreditation as a responsive, dialogical process that evolves in step with societal and technological change.

By tracing how through the lens of Engineering Education 5.0, Industry 5.0 is framed and enacted through accreditation, the study underscores that the future of engineering education will not be determined solely by industrial demands or pedagogical ideals. Rather, it will be co-constructed through the interplay of professional bodies, institutions, educators, and students, each contributing to the negotiation of what engineering should be in an Industry 5.0 era.

6.8 Final reflection

This thesis began with a recognition of the researcher's own positionality: an engineering educator and professional with over three decades of experience, deeply embedded in the structures and practices of accreditation, and in the development of strong links between industry and academia. This background inevitably shaped the question posed, the lens through which data were interpreted, and the priorities that emerged. At the same time, the study has provided the researcher with the opportunity to step back and critically interrogate the very structures that have framed much of her professional life.

Engaging with accreditation as a case study has been both affirming and challenging. It has affirmed the importance of accreditation as a mechanism for assuring quality and safeguarding standards. Yet it has also highlighted how accreditation frames educational priorities in particular ways, sometimes silencing or marginalising competencies that are increasingly central to preparing graduates for Industry 5.0. This realisation has prompted the researcher to reconsider long-held assumptions about what accreditation does and how it functions.

The use of Ball's (1993) policy cycle framework has been instrumental in shaping this critical perspective, revealing how policy is not a static directive but a process of continuous negotiation across contexts of influence, text production, and practice. Applying this framework has encouraged the researcher to view accreditation as an evolving policy discourse that both reflects and shapes wider transformations in engineering education.

The study has also been a journey of professional transformation. By interrogating how accreditation practices construct meanings around Industry 5.0, specifically, sustainability, ethics, and human-centricity, the researcher has become more attentive to how teaching and programme design can unintentionally reproduce narrow framings. This awareness has led to a more deliberate approach in the classroom, one that seeks to foreground inclusivity, adaptability, and student voice. In this way, the research has generated academic insights and also reshaped day-to-day practice.

Reflexivity has been central to this journey. At the outset, the researcher acknowledged that their insider perspective could be both a strength and a source of bias. By the end of the study, this reflexive stance has become a resource for interpreting findings in context and recognising how personal experience intersects with professional practice. The process of engaging with interviews, accreditation texts, and institutional documents has sharpened an appreciation of how meaning is negotiated in practice, and how accreditation itself is part of a wider dialogue about what it means to be an engineer in the twenty-first century.

Recent developments, such as the SEFI (2025) Skills Position Paper[20] further underscore the timeliness of this research. That paper explicitly situates European engineering education within the emerging Fifth Industrial Revolution, calling for greater emphasis on human-AI interaction, sustainability, and ethical responsibility principles that mirror the findings of this study. The alignment between these international policy directions and the study's conclusions reinforces the continuing relevance of examining accreditation as a key mechanism for realising Industry 5.0 values in practice.

Ultimately, this reflection reinforces the importance of maintaining openness to new interpretations, to emerging literatures, and to the voices of others in the accreditation process. The study has shown that neither Industry 5.0 nor the associated Engineering Education 5.0 model can be captured as fixed or definitive. Instead, they are evolving constructs, shaped through ongoing interaction among professional bodies, institutions, educators, and students. For the researcher, this

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[20] https://www.sefi.be/wp-content/uploads/2025/03/SEFI-Skills-position-paper-2025-1.pdf

is both a scholarly insight and a personal commitment: to continue engaging with accreditation and engineering education as dynamic spaces where new possibilities are constantly being constructed.

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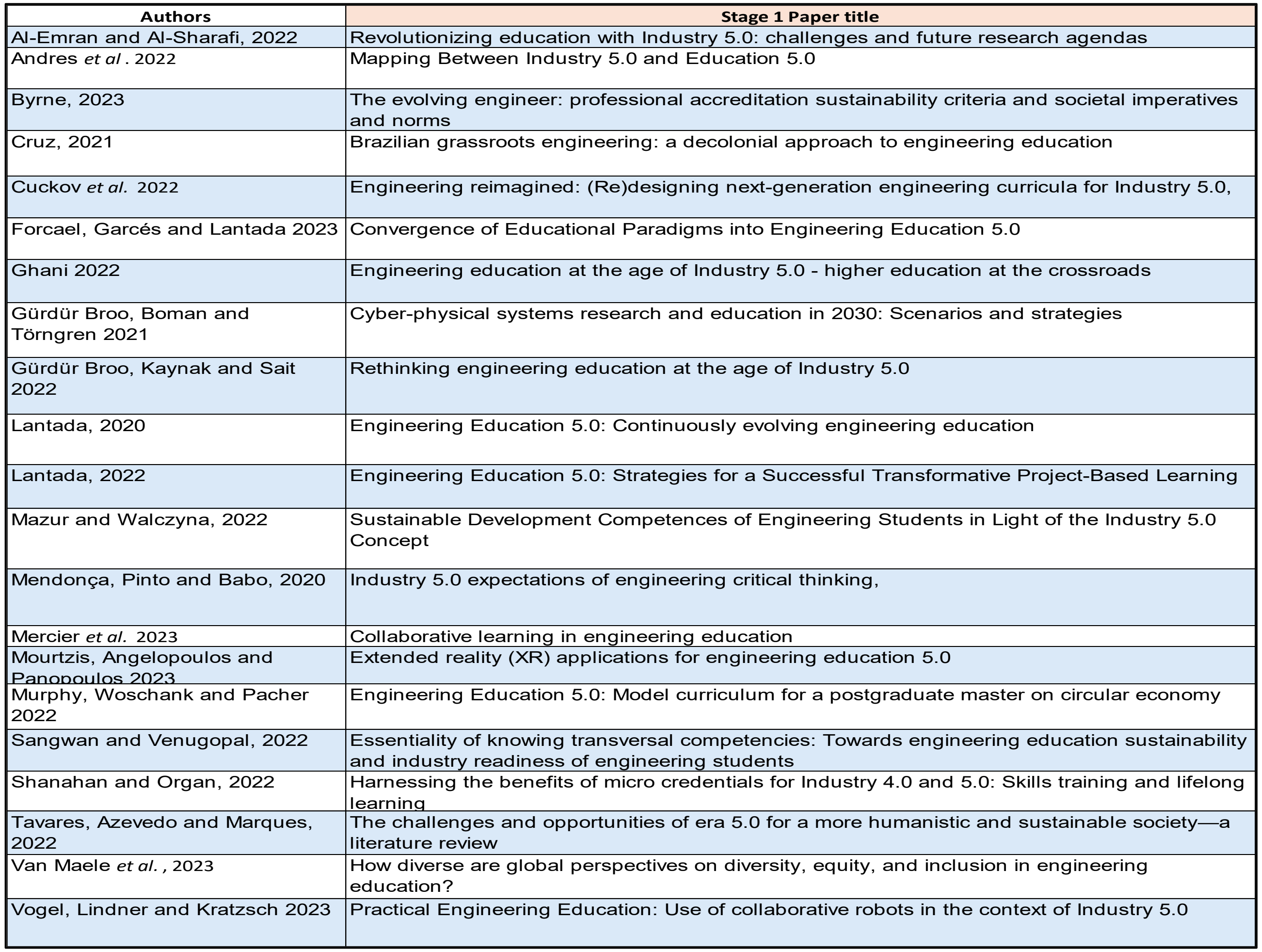
Appendix A Corpus of papers selected for Engineering Education 5.0 model refinement



Authors	**Stage 1 Paper title**
Al-Emran and Al-Sharafi, 2022	Revolutionizing education with Industry 5.0: challenges and future research agendas
Andres *et al* . 2022	Mapping Between Industry 5.0 and Education 5.0
Byrne, 2023	The evolving engineer: professional accreditation sustainability criteria and societal imperatives and norms
Cruz, 2021	Brazilian grassroots engineering: a decolonial approach to engineering education
Cuckov *et al.* 2022	Engineering reimagined: (Re)designing next-generation engineering curricula for Industry 5.0,
Forcael, Garcés and Lantada 2023	Convergence of Educational Paradigms into Engineering Education 5.0
Ghani 2022	Engineering education at the age of Industry 5.0 - higher education at the crossroads
Gürdür Broo, Boman and Törngren 2021	Cyber-physical systems research and education in 2030: Scenarios and strategies
Gürdür Broo, Kaynak and Sait 2022	Rethinking engineering education at the age of Industry 5.0
Lantada, 2020	Engineering Education 5.0: Continuously evolving engineering education
Lantada, 2022	Engineering Education 5.0: Strategies for a Successful Transformative Project-Based Learning
Mazur and Walczyna, 2022	Sustainable Development Competences of Engineering Students in Light of the Industry 5.0 Concept
Mendonça, Pinto and Babo, 2020	Industry 5.0 expectations of engineering critical thinking,
Mercier *et al.* 2023	Collaborative learning in engineering education
Mourtzis, Angelopoulos and Panopoulos 2023	Extended reality (XR) applications for engineering education 5.0
Murphy, Woschank and Pacher 2022	Engineering Education 5.0: Model curriculum for a postgraduate master on circular economy
Sangwan and Venugopal, 2022	Essentiality of knowing transversal competencies: Towards engineering education sustainability and industry readiness of engineering students
Shanahan and Organ, 2022	Harnessing the benefits of micro credentials for Industry 4.0 and 5.0: Skills training and lifelong learning
Tavares, Azevedo and Marques, 2022	The challenges and opportunities of era 5.0 for a more humanistic and sustainable society—a literature review
Van Maele *et al.* , 2023	How diverse are global perspectives on diversity, equity, and inclusion in engineering education?
Vogel, Lindner and Kratzsch 2023	Practical Engineering Education: Use of collaborative robots in the context of Industry 5.0

Authors	Stage 2 Paper title
Al-Emran and Al-Sharafi, 2022	Revolutionizing education with Industry 5.0: challenges and future research agendas
Andres *et al* . 2022	Mapping Between Industry 5.0 and Education 5.0
Cuckov *et al.* 2022	Engineering reimagined: (Re)designing next-generation engineering curricula for Industry 5.0,
Forcael, Garcés and Lantada 2023	Convergence of Educational Paradigms into Engineering Education
Ghani 2022	Engineering education at the age of Industry 5.0 - higher education at the crossroads
Gürdür Broo, Kaynak and Sait 2022	Rethinking engineering education at the age of Industry 5.0
Lantada, 2020	Engineering Education 5.0: Continuously evolving engineering
Lantada, 2022	Engineering Education 5.0: Strategies for a Successful Transformative Project-Based Learning
Mazur and Walczyna, 2022	Sustainable Development Competences of Engineering Students in Light of the Industry 5.0 Concept
Mendonça, Pinto and Babo, 2020	Industry 5.0 expectations of engineering critical thinking,
Mourtzis, Angelopoulos and	Extended reality (XR) applications for engineering education 5.0
Shanahan and Organ, 2022	Harnessing the benefits of micro credentials for Industry 4.0 and 5.0: Skills training and lifelong learning
Tavares, Azevedo and Marques, 2022	The challenges and opportunities of era 5.0 for a more humanistic and sustainable society—a literature review
Vogel, Lindner and Kratzsch 2023	Practical Engineering Education: Use of collaborative robots in the context of Industry 5.0

Authors	Stage 3 Paper title
Cuckov *et al.* 2022	Engineering reimagined: (Re)designing next-generation engineering curricula for Industry 5.0,
Forcael, Garcés and Lantada 2023	Convergence of Educational Paradigms into Engineering Education 5.0
Ghani 2022	Engineering education at the age of Industry 5.0 - higher education at the crossroads
Gürdür Broo, Kaynak and Sait	Rethinking engineering education at the age of Industry 5.0
Lantada, 2020	Engineering Education 5.0: Continuously evolving engineering education
Mendonça, Pinto and Babo, 2020	Industry 5.0 expectations of engineering critical thinking,
Mourtzis, Angelopoulos and	Extended reality (XR) applications for engineering education 5.0
Vogel, Lindner and Kratzsch 2023	Practical Engineering Education: Use of collaborative robots in the context of Industry 5.0

Appendix B Interview schedule

Section	Purpose	Possible Questions
1. Introduction	1. Organisation 2. Interviewee 3. Understanding of terms	1. Can you tell me how you came to be on the accreditation panel 2. Outline your background and experience?
2. Exploration (1)	1. The EIAD dev process 2. The influences 3. The outcome	1. I'm interested in the how the accred doc was put together. Could you explain to me how it was constructed? 2. Who were the stakeholders? 3. Why were they chosen? 4. Outline any training received for the dev of the criteria. 5. Outline your understanding of "who informs" the EIAD? (positionality of EI) 6. Outline the criteria development process i.e. how did you go about constructing this document? 7. How were differing opinions dealt with? 8. There are a number of changes. Explain the changes from the previous version? 9. In your own words, what is your understanding of EI POs and PAs? 10. Why is Sustainability a PA? 11. New PO, PO8 – discuss – what led to this becoming a new PO? 12. Coverage of data science, analytics and the ethical usage of technology and data – where is this evident in the doc? 13. Coverage of equality, diversity and inclusion in professional practice, teamwork and communication; - why this emphasis and why now? discuss 14. Is there a process in place to determine if the accreditation criteria are a success? 15. Future review plans - The criteria doc is now 3 years old – in moving to the next set of criteria is there anything you think should be included or omitted? why
3. Exploration (2)	1. Industry 5.0/EE 5.0 - The features	1. My research is looking at EE5.0 (how EE influenced by Industry 5.0. What is your understanding

	2. The intersectionality with EIAD	(if any) of Industry 5.0 and/or Engineering Education 5.0? 2. Use table below for each feature – discuss each separately. Do you agree that/what is your opinion of engineering education wrt the following features? 3. Where do you imagine the most crossover is in the POs for each feature? 4. Is there anything that surprises you about these features?
4. Summation	1. Summarising (interviewer) 2. Benefit for interviewee. 3. Completeness 4. Acknowledgement and exit	1. Summarise and ascertain feedback on accurateness (interviewer) 2. How do you feel about summary ? 3. Exit statement and thanks

Appendix C Informed Consent Form

Informed Consent Form (ICF):

An exploration of the 2021 Engineers Ireland accreditation criteria to affirm if the updated Programme Outcomes reflect societal needs in the era of Industry 5.0/Engineering Education 5.0.

Purpose of the Research

This study explores the extent of the features of Engineering Education 5.0* present in engineering programmes in Ireland. As such, it seeks to examine the most recent Engineers Ireland accreditation criteria with a view to understanding how the accreditation board developed the criteria.

*the features of Engineering Education 5.0 are:

1. Technical Competency, 2. Sustainability, 3. Ethics & Social Impact, 4. Collaboration, 5. Educational Approach, 6. Global and Cultural Perspectives, 7. Holistic & Human-centricity

Requirements of participation in this research study

Your participation in this study involves an online interview. I would like to talk to you about the involvement in the Engineers Ireland Accreditation board. The focus of the interview is for me to learn more about Engineers Ireland's accreditation development process. I hope to use your answers to enable me to better understand if and how the features of Engineering Education 5.0 are embedded in engineering programme curricula. I can provide you with a list of topics that I would like to address in advance of our interview.

You do not have to take part unless you want to, and you may decide not to be involved in the study. If you have any questions about my study, I would be happy to answer them. Although interviews will be audio-recorded with an audio recording device, recordings will not be shared with anybody, and your name will not be used in any written report. A summary of the main research findings will be made available to you.

Confirmation that involvement in the research study is voluntary.

Please complete the following (Circle Yes or No for each question).

I am aware that if I agree to take part in this study that I can withdraw from participation. There will be no penalty for withdrawing. Yes/No

I have read (or had read to me) the Plain Language Statement Yes/No

I understand the information provided in the Plain Language Statement Yes/No

I have had an opportunity to ask questions and discuss this study Yes/No

I have received satisfactory answers to all of my questions Yes/No

I understand that I will be interviewed to describe my knowledge of the development of Industry 5.0. Yes/No

I understand that these interviews will be recorded Yes/No

I have read and understood the information in this form. The researcher has answered my questions and concerns, and I have a copy of this consent form. Therefore, I give my consent to take part in this research project.

Participant signature: _________

Participant Name in Block Capitals: _____________

Date: _______________________

Appendix D Plain Language Statement

Dear Engineers Ireland accreditation board member

My name is Louise O'Gorman, and I am asking if you would agree to be interviewed as part of my research. I am a part-time doctoral student at DCU and am a full time employee of the faculty of engineering in ATU Sligo. You have been selected for this study because you are a member of Engineers Ireland accreditation board.

Please read the following plain language statement as it outlines the information you need to know regarding this study and what will be expected of you as a participant in this research.

Aims and purpose of the research

This study explores the extent of the features of Engineering Education 5.0* present in engineering programmes in Ireland. As such, it seeks to examine the most recent Engineers Ireland accreditation criteria with a view to understanding how the accreditation board developed the criteria.

*the features of Engineering Education 5.0 are:

1. *Technical Competency*
2. *Sustainability*
3. *Ethics & Social Impact*
4. *Collaboration*
5. *Educational Approach*
6. *Global and Cultural Perspectives*
7. *Holistic & Human-centricity*

Why is this research important?

This research is important because it may inform Engineers Ireland on its next iteration of accreditation criteria. It will also inform engineering programme boards in HEIs on best practice in meeting the accreditation criteria. Finally, individual participants will receive my findings which may help them to understand and improve their professional practice.

What will you have to do?

Your participation in this study involves an interview, online or in person, whichever you feel most comfortable with. The focus of the interview is for me to learn more about the Engineers Ireland accreditation development process. I hope to use your answers to enable me to better understand if and how the features of Engineering Education 5.0 are embedded in engineering programme curricula. I can provide you with a list of topics that I would like to address in advance of our interview.

I will not disclose any details of this interview (except to my supervisors) to any third parties. The interview will last no longer that one hour.

What are the benefits?

The information I collect will be analysed and my findings will be shared with you. In your role as Engineers Ireland accreditation board member, you may benefit from the results in two ways. Firstly, you will have evidence to show if the features of Engineering Education 5.0 are currently embedded into engineering programme curricula. Secondly, the results could inform your own professional practice.

What are the risks to you?

There are no known risks associated with participating in this study. There are no 'right' or 'wrong' answers to the questions in the interview; it is just a conversation about your knowledge and experience of the accreditation development process in Ireland. If you would prefer not to answer any question in the interview you can just skip them. During the research, you can withdraw from participating and your decision will be respected without question.

What happens to the information?

This information will be analysed to inform my research as part of a final doctoral thesis and for peer reviewed papers. My doctoral study is funded by my employer, ATU Sligo. Your name will be replaced to provide anonymity in research publications. However, despite my best efforts, due to the small sample size I cannot guarantee your anonymity. The recording of the focus groups and interviews will be stored on a password encrypted Google Drive. The confidentiality of information provided by you will be protected within the limitations of the law i.e., it is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

What happens at the end of the study?

With respect to the information you have provided to me during the interview, all audio files and transcripts will be deleted, in accordance with DCU Data Protection Policy. However, if you have any concerns, you have the right to lodge a complaint with the Irish Data Protection Commission.

What happens if I have more questions or do not understand something?

If you have any questions or concerns, please do not hesitate to contact me at any stage. Alternatively, you may wish to contact my supervisors: Professor Mark Brown - Mark.brown@dcu.ie, Dr Margaret Leahy - Margaret.leahy@dcu.ie or Dr Paul Young - Paul.young@dcu.ie or the DCU Data Protection Officer – Mr. Martin Ward. (data.protection@dcu.ie Ph.: 01 7005118 / 7008257).

What happens if I have more questions or do not understand something?

You are free to opt out of the interview without any consequences.

Sincere thanks for reading this information letter and for considering your participation in this proposed study.

Yours sincerely,

____

Louise O'Gorman

Louise.ogorman7@mail.dcu.ie

Appendix E Ethics approval

Ollscoil Chathair Bhaile Átha Cliath
Dublin City University

DCU

Professor Mark Brown
School of School of STEM Education, Innovation & Global

Studies 18th May 2023

REC Reference: DCUREC/2023/093

Proposal Title: An exploration of Engineers Ireland accreditation criteria to affirm if engineering programmes are fit for purpose in the new era of Industry 5.0.

Applicant(s): Prof Mark Brown, Dr Paul Young, Ms Louise O'Gorman

Dear Colleagues,

Thank you for your application to DCU Research Ethics Committee (REC). Further to notification review, DCU REC is pleased to issue approval for this research proposal.

DCU REC's consideration of all ethics applications is dependent upon the information supplied by the researcher. This information is expected to be truthful and accurate. Researchers are responsible for ensuring that their research is carried out in accordance with the information provided in their ethics application.

Materials used to recruit participants should note that ethical approval for this project has been obtained from the Dublin City University Research Ethics Committee. Should substantial modifications to the research protocol be required at a later stage, a further amendment submission should be made to the REC.

Yours sincerely,

DCU
Research & Innovation

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Dr. Melrona Kirrane
Chairperson
DCU Research Ethics Committee

Note: Please retain this approval letter for future publication purposes (for research students, this includes incorporating the letter within their thesis appendices)