INTELLIGENT TECHNOLOGIES IN EDUCATION

A GenAI Competence Framework for Engineering Curriculum Enhancement in Higher Education

Yue Chen[a], Kok Keong Chai[a], Vindya Wijeratne[a], Usman Naeem[a], Jonathan Loo[a], Xue Zhou[b], Simon Lucas[a]

[a] School of Electronic Engineering and Computer Science, Queen Mary University of London, London, UK
[b] School of Marketing and Strategy, University of Leicester, Leicester, UK

Abstract

This paper proposes a Generative Artificial Intelligence (GenAI) Competence Framework for Engineering Curriculum Enhancement, designed to leverage GenAI's potential to enrich teaching and learning, address challenges arising from misuse or unethical application of GenAI, and prepare graduates for AI-driven workplaces. Building upon the university's AI literacy framework, this conceptual GenAI Competence Framework provides actionable guidelines on embedding GenAI competence development in the Engineering Curriculum. It defines structured competence tiers, outlines strategies for curriculum integration, offers practical implementation plans, and establishes impact assessment mechanisms. These four elements collectively form an adaptive and continuous improvement cycle, ensuring the framework remains responsive to technological advancements and evolving stakeholder needs. Emphasising practicality, adaptability, ethics, and alignment with real-world demands, the framework aims to provide a robust foundation for equipping students with essential GenAI competencies while enriching their overall learning experience.

Section: Educational Technology (General Articles)

Editor-in-Chief: Dr Marios Kremantzis
Associate Editor: A/Prof Eleonora Pantano

Publication

Received: 11 January 2025
Revised: 1 May 2025
Accepted: 11 June 2025
Online: 12 June 2025

Keywords

GenAI, AI Competence, AI in Teaching and Learning, Engineering Education, Higher Education

Citation

Chen, Y., Chai, K.K., Wijeratne. V., Naeem. U., Loo. J., Zhou. X. & Lucas. S. (2025). A GenAI Competence Framework for Engineering Curriculum Enhancement in Higher Education. *Intelligent Technologies in Education*, Advanced Online Publication.

Introduction

Artificial Intelligence (AI) Education is not new to Engineering curricula. Modules such as *Introduction to AI*, *Machine Learning*, and *Deep Learning* cover foundational knowledge and specialised techniques on AI, while technical modules explore AI applications and implications within specific domains. However, the advent of Generative AI (GenAI) has had a profound impact on the education sector due to its ability to generate new content and respond to prompts in a personalised manner. This shift has transformed learning approaches and brought new challenges in maintaining academic integrity, as solutions to conventional assessments, such as essays and coding assignments, can now be largely generated by GenAI tools.

With widely accessible GenAI tools, such as ChatGPT, which have transformed numerous industries, it is increasingly envisioned that future employees will no longer work independently of AI but instead collaborate with it as a standard part of their roles. In fields such as engineering, medicine, and data science, professionals are expected to leverage AI tools to enhance productivity, drive innovation, and support complex decision-making processes (Rashid and Kausik, 2024). As such, there is an urgent need for the education sector, including schools, colleges, universities, and Continuing Professional Development (CPD) programmes, to revisit their educational content and pedagogy to respond to this rapidly changing technology (Kamalov et al., 2023).

Since late 2022, the importance of AI literacy, and specifically GenAI literacy, has gained significant attention. Several models and frameworks have been developed to enhance GenAI competence among learners and educators, with a primary focus on policies and training initiatives (Southworth et al., 2023; Ng et al., 2023). However, practical GenAI competence cannot be fully built unless these efforts are embedded directly into the curriculum. In this paper, we propose a comprehensive GenAI Competence Framework which builds upon the university's conceptual framework for AI literacy (Zhou and Schofield, 2024) and is specifically tailored to enhance the Engineering curriculum which already incorporates conventional AI education. The aim of this framework is to provide a holistic approach to curriculum enhancement, integrating progressive learning strategies to ensure students graduate with the GenAI competence required in the modern workforce.

The framework addresses the following research questions:

1. How should GenAI competence be defined within the context of higher education, particularly for Engineering degrees?
2. What changes are necessary in Engineering curriculum design to equip students with practical GenAI competence?
3. What strategies can ensure the effective implementation of these changes, and how can their impact be systematically evaluated?
4. How can the proposed framework remain sustainable and adaptable in a rapidly evolving technological landscape?

By addressing these research questions, the conceptual framework is structured around four core elements: defining GenAI competence within the context of Engineering education; identifying necessary curriculum changes to equip students with practical GenAI skills; formulating strategies for effective implementation and systematic impact evaluation; and ensuring sustainability and adaptability of the framework in the face of rapidly evolving technology. These elements collectively support the development of GenAI competencies, preparing engineering graduates to meet the demands of a GenAI-integrated world.

Literature Review

Evolving Notions of Literacy and Digital Competence

The definition of *Literacy* has evolved considerably beyond its traditional focus on reading and writing. Modern interpretations now incorporate a wide range of capabilities, including critical thinking, communication, and digital navigation, required for effective engagement in contemporary society. For instance, the UK's National Literacy Trust includes speaking and listening within the scope of literacy (National Literacy Trust, n.d.), while *Digital Literacy*, focuses on the ability to find, evaluate, utilise, share, and create content using information technologies and the internet (Reddy, Sharma, and Chaudhary, 2020), reflecting the dynamic demands of modern education and the workforce.

This evolution has been supported by the development of formalised digital competence frameworks, such as the *European Digital Competence Framework (DigComp)*, DigComp 2.0 (Brande et al., 2016), and DigComp 2.1 (Carretero, Vuorikari and Punie, 2017), which outline progressive levels of proficiency in digital skills such as communication, content creation, safety and problem-solving. International adaptations, such as the *International Society for Technology in Education (ISTE) Standards* in the United States (International Society for Technology in Education, n.d.), Singapore's *Digital Readiness Blueprint* (Ministry of Communications and Information, 2018), and UNESCO's *Digital Literacy Global Framework* (UNESCO, 2018), demonstrating a shared global commitment to equipping individuals with the skills necessary to thrive in increasingly digital and interconnected societies. However, these frameworks tend to generalise digital skills and lack focus on emerging technologies such as GenAI or discipline-specific needs.

The Rise of AI and GenAI Literacy

The increasing integration of AI into education has catalysed the emergence of AI literacy as a key educational priority. Early discussions around AI literacy focused on general awareness and understanding of AI's capabilities, limitations, and ethical implications. As AI tools became more accessible, the definition expanded to include practical skills, such as designing, using, and interpreting AI systems. According to Ng et. al (2021), there are four aspects of fostering AI literacy: know and understand AI; use and apply AI; evaluate and create AI; and AI ethics. This work has set the groundwork for research on competency development and assessment criteria on AI literacy. UNESCO's AI and Education report (UNESCO, 2021) outlines strategies for embedding AI literacy into national education systems, with an emphasis on inclusivity and lifelong learning.

The emergence of GenAI technologies such as OpenAI's ChatGPT and DALL-E, prompted a further shift, introducing a distinct set of competencies. These include prompt engineering (Hill et. al, 2024), critical evaluation of AI outputs (Thiga, 2024), and understanding the underlying mechanisms of generative models (García-Peñalvo et. al., 2023). These skills are now viewed as essential for preparing individuals to engage with AI-driven tools in meaningful and responsible ways.

Global organisations have begun articulating the implications of GenAI for education. UNESCO (2023) calls for regulation and ethical safeguards in GenAI use, while OECD (2023) examines the opportunities and challenges of integrating generative AI in educational settings and provides guidelines and guardrails to ensure effective and equitable use of AI. The World Economic Forum (2024) highlights AI's potential to personalise learning experiences, streamline administrative tasks, and integrate into curricula. Despite these calls to action, practical strategies for embedding GenAI competencies into higher education curricula remain underdeveloped.

Existing Frameworks, Empirical Studies and Their Limitations

The emergence of GenAI literacy initiatives and related policies has catalysed efforts to develop comprehensive frameworks aimed at integrating AI competencies into education and workforce training. For example, Ng et. al expanded their work (Ng et. al, 2021) by adapting the DigCompEdu framework to outline key AI competencies for teachers, including professional engagement, the use of digital resources, AI-supported teaching, and assessment (Ng et. al, 2023); Cha et. al, (2024) proposed a teacher competency framework that includes three intersecting components: self-empowerment competency, professional and pedagogical competency, and empowerment competency, aiming to transform university teachers from domain-specific experts to well-rounded educators; Bozkurt (2024) proposed a 3wAI Framework, encompassing the dimensions of Know What, Know How, and Know Why. The work argues that GenAI literacy is crucial for surviving the complexities of human-machine interaction and properly leveraging this technology, especially in educational settings; Shailendra et. al, (2024) proposed a 4E framework (Embrace, Enable, Exploit, and Experiment) to promote adoption of GenAI in the university curriculum. It recognises the roles of different stakeholders and defines an evaluation matrix to measure the effectiveness and success of the adoption process.

A growing body of empirical work has also examined AI literacy in educational contexts. Wut et al. (2025) found that students' perceived AI literacy significantly influenced their sense of employability, especially when trust in AI tools was high. Tzirides et al. (2024) showed that engaging with GenAI platforms improved student confidence, competence, and familiarity with AI. Kim et al. (2025) demonstrated that carefully designed AI learning datasets improved student performance in problem-solving and data literacy tasks, while Özden et al. (2025) identified a modest positive correlation between pre-service teachers' attitudes towards AI and their literacy levels. Despite these promising developments, notable limitations persist. Many empirical studies rely heavily on self-reported data, are conducted within narrow institutional settings, and do not sufficiently address the curricular transformations necessary to scale GenAI competence development. Furthermore, existing research often overlooks the specific regulatory, ethical, and technical complexities associated with GenAI applications, particularly within Engineering curricula.

The aforementioned frameworks and empirical studies provide a solid foundation for understanding the impact of GenAI on education and offer valuable recommendations for cultivating GenAI-related skills within universities. However, a critical gap remains in the systematic integration of these competencies into existing curricula, particularly within

Engineering degree programmes that already incorporate conventional AI education. While frameworks such as DigComp, 3wAI, and 4E have laid important groundwork for AI and GenAI literacy, there is a clear and pressing need for a structured approach that not only aligns with the broader evolution of digital and AI literacies but also contextualises these competencies within the unique demands of human-machine interaction in the Engineering domain.

The GenAI Competence Framework proposed in this paper addresses this gap by combining a three-tier model of competence development with curriculum-specific integration guided by the TPACK framework. It also embeds ethical, legal, and regulatory considerations across all levels of technical engagement. This comprehensive approach offers a scalable and discipline-sensitive strategy for embedding GenAI skills in Engineering education.

The GenAI Competence Framework

Our design of the GenAI Competence Framework for Curriculum Enhancement is grounded in the specific nature and expectations of Engineering degrees in the UK. These degrees are shaped by the Quality Assurance Agency for Higher Education (QAA) *Engineering Benchmark Statement* (QAA, 2023), accreditation requirements from Professional, Statutory, and Regulatory Bodies (PSRBs), e.g. the Engineering Council, and the evolving needs of the AI-driven workforce. These guidelines emphasise equipping students with a blend of theoretical knowledge, technical skills, and ethical awareness necessary for success in professional practice.

In this context, GenAI competence is defined as the ability to effectively and responsibly engage with GenAI technologies across foundational, technical, and domain-specific levels. Within Engineering higher education, this involves understanding core GenAI principles, applying tools to solve engineering problems, and addressing the ethical, legal, and societal implications of GenAI use.

Framework Overview

Figure 1 illustrates the proposed GenAI Competence Framework for Curriculum Enhancement, which operates through a cyclical, closed-loop structure that promotes human-centred learning.

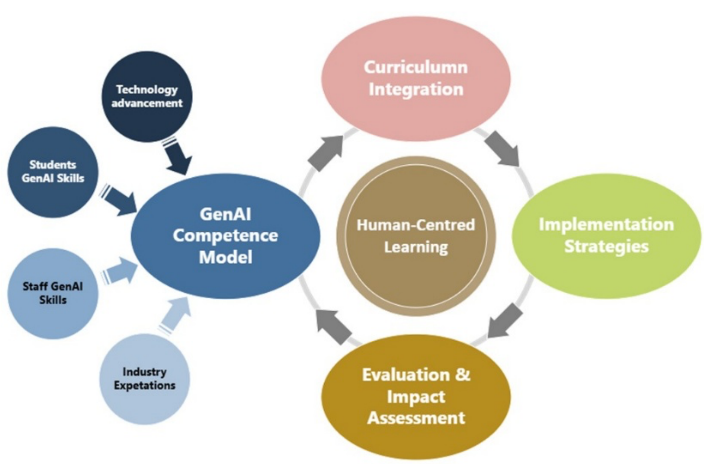

Figure 1

GenAI Competence Framework for Curriculum Enhancement

The framework comprises four interconnected elements: *the GenAI Competence Model, Curriculum Integration, Implementation Strategies*, and *Evaluation & Impact Assessment*. Together, these components form a dynamic cycle that enables continuous improvement and adaptation to technological advancements, evolving industry expectations, and changing educational needs. In particular, *the GenAI Competence Model* is subject to regular review, taking into account the impact of emerging technologies, employer requirements, and the evolving GenAI capabilities of both students and staff.

Framework Elements

GenAI Competence Model

In the context of Engineering education, our GenAI Competence Model addresses the dual need for both foundational GenAI literacy and advanced GenAI competence. Foundational GenAI literacy encompasses basic understanding, responsible use, prompt engineering, and general applications, while advanced GenAI competence includes technical proficiency, domain-specific applications, problem-solving, and creativity.

Building upon the university's conceptual framework for AI literacy (Zhou and Schofield, 2024) and drawing inspiration from DigComp's progressive levels of proficiency in digital skills, we define the GenAI Competence Model using a three-tier structure grounded in established pedagogical theories, as shown in Figure 2. The tiered model outlines a clear developmental trajectory for GenAI competence, with each tier explicitly aligned to specific cognitive levels defined in Bloom's Revised Taxonomy (Anderson, 2001). Tier 1 focuses on foundational knowledge and understanding; Tier 2 emphasises application and analysis; and Tier 3 advances to synthesis, evaluation, and creation in real-world problem-solving contexts. This progression is designed to cultivate higher-order cognitive skills, enabling learners to move beyond basic tool usage toward critical, reflective, and creative engagement with GenAI technologies. The three progressive tiers build sequentially, enabling students to develop comprehensive GenAI expertise while placing consistent emphasis on Ethical, Legal, and Regulatory (ELR) considerations across all tiers.

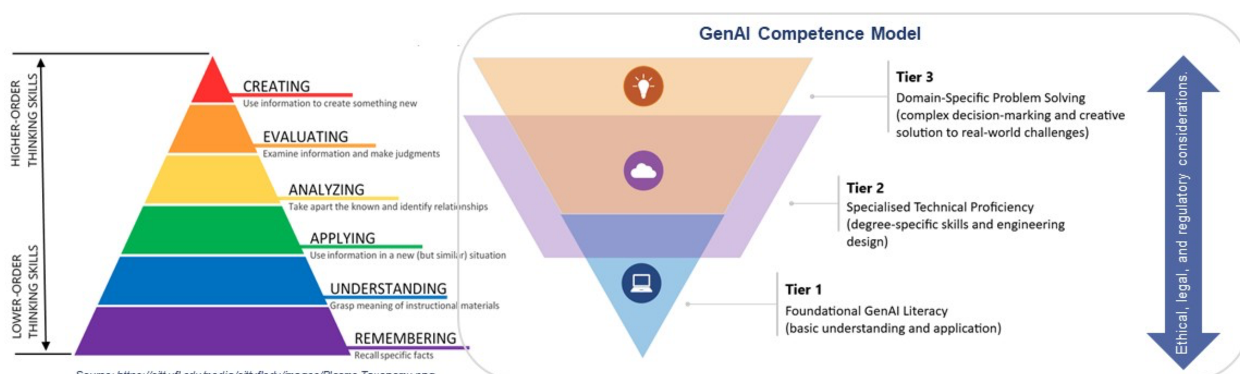

Figure 2

GenAI Competence Model

Competence Tiers

Tier 1: Foundational GenAI Literacy

This level focuses on basic understanding and responsible use of GenAI. Students gain knowledge of prompt engineering, general applications of GenAI tools, and their potential impact. It covers the ability to recognise the role of training data, machine learning models, and outputs, while fostering skills to apply GenAI tools in simple tasks. This tier aligns with the lower three cognitive levels (remembering, understanding, and applying) in Bloom's Taxonomy.

Tier 2: Specialised Technical Proficiency

At this stage, students develop proficiency in using GenAI for technical tasks such as data analysis, engineering design, problem-solving, and optimising and fine-tuning GenAI models for specific engineering applications. This tier aligns with higher cognitive levels in Bloom's Taxonomy, such as applying, analysing, and evaluating.

Tier 3: Domain-Specific Problem Solving

The highest level of competence focuses on the advanced application of GenAI in specialised engineering domains. It involves integrating human creativity with GenAI tools to tackle complex, real-world challenges. This tier aligns with the top three higher-order cognitive levels (analysing, evaluating, and creating) in Bloom's Taxonomy. Students are encouraged to synthesise information, innovate solutions within their respective disciplines, and apply deep technical expertise and domain-specific knowledge to deliver impactful outcomes.

Ethical, Legal, and Regulatory Considerations

The proliferation of GenAI technologies has introduced a complex array of ELR challenges. These issues, particularly those surrounding ethics, bias, and data privacy, are especially pertinent in Engineering education, where AI-driven tools are increasingly used to inform technical design, automate decision-making, and analyse sensitive data. Embedding ELR considerations in GenAI competence development is essential to ensure responsible, equitable, and safe applications in practice (UNESCO, 2023; OECD, 2023).

AI Ethics

AI ethics provides the foundational principles guiding the development and deployment of AI technologies. For engineering contexts, ethical considerations are critical, particularly when AI influences design automation, safety-critical systems, or infrastructure management. Key principles include transparency, accountability, fairness, and respect for human autonomy (Floridi et al., 2018). Students must learn to identify and address ethical dilemmas associated with AI-generated solutions, recognising when AI recommendations may introduce harm, bias, or unintended consequences.

Bias in GenAI Systems

Bias in GenAI tools arises from training data, model design, and user prompts, often leading to inaccurate, unfair, or discriminatory outcomes. In engineering, this can result in unsafe systems, suboptimal resource allocation, or inequitable service delivery (Mehrabi et al., 2021). Addressing such bias requires both technical strategies, such as bias detection, mitigation, and fairness-aware design, and an understanding of broader social implications. Engineering students must acquire the ability to audit GenAI outputs and implement corrective measures to prevent systemic risks.

Data Privacy

The use of personal and sensitive data to train or prompt GenAI tools introduces considerable privacy risks. In engineering projects, especially those involving biomedical data, user behaviour analysis, or infrastructure monitoring, unauthorised data exposure may breach legal requirements such as the General Data Protection Regulation (GDPR) or Health Insurance Portability and Accountability Act (HIPAA). It is therefore critical that students are trained in privacy-preserving techniques, such as anonymisation, encryption, and differential privacy, to ensure compliance and data stewardship (Voigt & Von dem Bussche, 2017).

The GenAI Competence Model integrates ELR principles across all three developmental tiers, enabling progressive acquisition of ethical awareness and regulatory literacy.

Tier 1: Foundational GenAI Literacy

- **GenAI Ethics**: Students are introduced to core ethical principles such as fairness and accountability. Through case-based discussions and basic applications (e.g. using GenAI to generate designs, reports, and codes), they learn to identify ethical risks, cite AI assistance appropriately, and apply principles of academic integrity (Ng et al., 2021).
- **Bias Awareness**: Learners explore how biased prompts or training data can skew GenAI outputs. Activities include analysing simple outputs for representational bias or misalignment with engineering standards.
- **Data Privacy Basics**: Students gain an introduction to privacy, concepts consent, anonymisation, and secure handling, by evaluating scenarios where GenAI interacts with sensitive data, such as in biomedical or smart infrastructure contexts.

Tier 2: Specialised Technical Proficiency

- **Applied Ethics**: Students apply ethical reasoning to real-world engineering projects. For example, when using GenAI to optimise energy systems, they consider social equity and sustainability. They are also introduced to co-authorship practices and transparency in GenAI-human collaboration (Shailendra et al., 2024).
- **Bias Mitigation**: Learners gain proficiency in techniques such as prompt refinement, dataset curation, and algorithmic auditing to mitigate bias in technical applications, including fault prediction or structural analysis.
- **Privacy Implementation**: Students design privacy-aware solutions using encryption and access controls. They also examine regulatory compliance when working with datasets in smart city or IoT systems, aligning with relevant frameworks such as GDPR.

Tier 3: Domain-Specific Problem Solving

- **Advanced Ethical Reasoning:** At this level, students address complex ethical dilemmas in GenAI-integrated engineering systems. Examples include evaluating the trade-offs in deploying GenAI for automated safety inspections or manufacturing

process optimisation, with explicit reference to legal and societal standards (Floridi et al., 2018).
- **Bias Impact Assessment**: Students critically assess how GenAI bias may affect real-world engineering outcomes, such as urban planning or autonomous system design. They conduct fairness evaluations and propose mitigation strategies aligned with professional codes and industry norms.
- **Advanced Privacy Engineering**: Students tackle large-scale privacy issues, incorporating privacy-by-design principles in systems using high-sensitivity data. They explore advanced frameworks and legal implications, including data sovereignty and ethical data reuse (Voigt & Von dem Bussche, 2017).

By embedding ELR principles across the tiers of GenAI competence development, the framework ensures that students not only master technical skills but also develop ethical maturity and regulatory awareness. This integrated approach prepares future engineers to innovate responsibly in an increasingly AI-mediated professional landscape.

Curriculum Integration

To integrate the GenAI Competence Model into the curriculum, the framework adopts a staged progression aligned with the academic development years of a three- or four-year undergraduate engineering degree programme. This approach ensures that students progressively develop their GenAI competence from foundational literacy to advanced, domain-specific expertise. This integration is guided by the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra and Koehler, 2006), which emphasises the interconnected nature of technological, pedagogical, and content knowledge required for effective technology-enhanced teaching. In the context of GenAI integration, the TPACK framework provides a robust theoretical foundation for guiding educators in selecting appropriate GenAI tools (technological knowledge), aligning them with sound instructional strategies (pedagogical knowledge), and tailoring them to disciplinary content (content knowledge). This alignment ensures that GenAI integration is not merely tool-driven but is pedagogically sound and contextually relevant to Engineering education. Educators are thus supported in designing and delivering instruction that meaningfully incorporates GenAI while maintaining the integrity and coherence of disciplinary knowledge.

Stage 1: Awareness (Year 1)

Introduces foundational GenAI literacy, focusing on developing a basic understanding of GenAI tools and their ethical use in various engineering contexts. For example, students explore AI-based code assistants to write and debug introductory algorithms.

Stage 2: Application in Context (Year 2-3)

Emphasises hands-on application of GenAI in specific engineering tasks, fostering technical proficiency, contextual problem-solving, and a deeper understanding of GenAI capabilities. For example, students use GenAI to optimise computer network designs or model communication load distribution.

Stage 3: Mastery and Innovation (Years 3-4)

Focuses on advanced GenAI applications, encouraging critical thinking, creativity, innovation, and the development of domain-specific expertise to solve complex, real-world challenges. For example, students develop AI-powered solutions for energy-efficient Internet of Things (IoT) systems or create domain-specific GenAI models for predictive maintenance in cloud computing or autonomous system navigation.

The staged progressive learning is facilitated by conducting a programme review to identify modules[1] requiring updates within each degree programme. Based on the extent of necessary amendments, modules are classified into three categories. As shown in Figure 3, this classification provides a pragmatic roadmap for curriculum integration, guiding degree-level adaptations according to the scale of change required.

High-Level amendments

Significant AI up-skilling is required for specialised AI-focused modules and skill-based modules.

In the engineering context, the development of Tier 1 foundational GenAI literacy is facilitated through the introduction of a new first-year module, "Introduction to AI", added to all programmes. Consequently, the second-year module, *AI Foundations and Applications*, has undergone content adjustments to focus more extensively on practical applications of AI, including the use of GenAI tools and techniques. Furthermore, topics such as transformers, self-supervised learning, and diffusion models will take a central role in advanced modules, including "Machine Learning" and "Deep Learning", reflecting the evolving landscape of AI education.

For skill-based modules, such as “Communication Skills” and “Professional Skill Development”, the focus will shift to incorporating GenAI tools to enhance practical capabilities. For example, students will use LLMs to generate and refine technical documentation, improve presentations, and facilitate collaborative problem-solving. Additionally, emphasis will be placed on prompt engineering techniques, ethical considerations in AI-assisted communication, and critical evaluation of GenAI-generated outputs to ensure accuracy, clarity, and professional integrity. These enhancements aim to equip students with the skills to effectively integrate GenAI tools into professional and academic workflows.

Medium-Level amendments

Moderate updates to module content are needed to incorporate GenAI applications and their implications, particularly for degree-specific technical modules.

For instance, the module "Principles of Telecommunication Systems" will include new content on the use of GenAI for generating synthetic data, enabling large-scale simulations that were previously challenging to conduct. This enhancement highlights the transformative potential of GenAI in advancing simulation capabilities and solving complex engineering problems.

---

[1] *Modules requiring updates may vary across degree programmes.*

Low-Level amendments

No changes to module content are necessary for modules in this category; however, assessments need to be re-designed to safeguard against potential misuse of GenAI tools.

The content of most foundation modules in engineering degree programmes remains unchanged, as their core knowledge and skills are essential for building a strong base in the relevant engineering fields. However, conventional assessments, such as solving mathematical equations or performing routine computational tasks, risk becoming ineffective due to the ease with which they can be completed using GenAI tools. Moreover, reliance on these traditional methods may inadvertently encourage some students to develop habits of over-dependence on GenAI, potentially undermining academic integrity. To address this, assessments will be redesigned to prioritise critical thinking, problem-solving, and a deeper conceptual understanding, shifting the focus from evaluating the final output to assessing the problem-solving process.

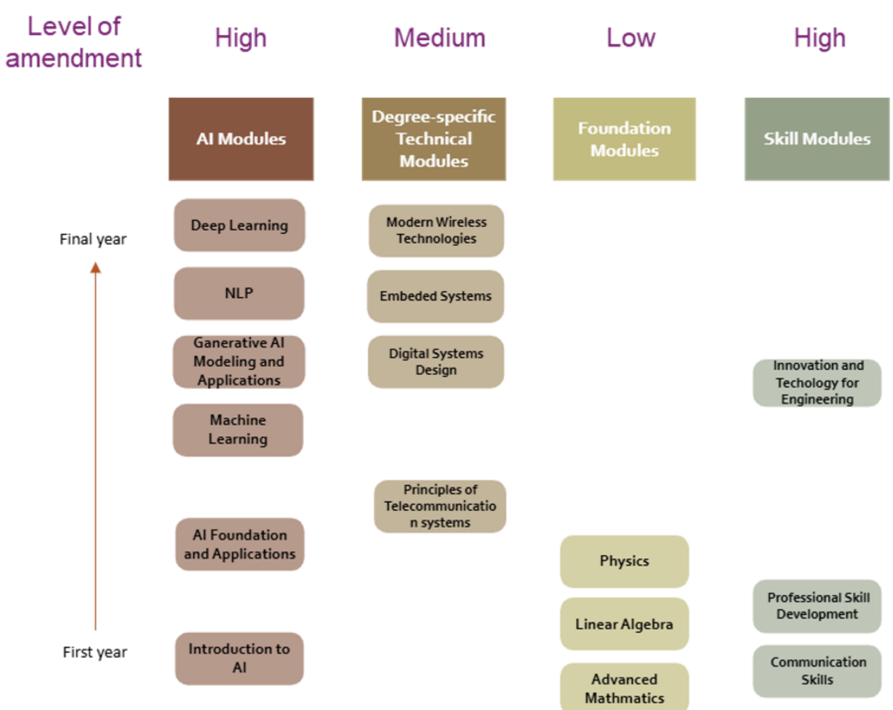

Figure 3

Level of amendment for GenAI integration across different module types[2]

---

[2] *Note: This figure provides a representative selection of modules; not all modules are shown.*

Pedagogical and Delivery Considerations

In addition to module content updates, the pedagogy and delivery methods of all modules must also be reconsidered. Traditional didactic lectures should be replaced or supplemented with more interactive and student-centred approaches to enhance engagement and facilitate active learning. For example, the Guided Personalised Learning (GPL) model proposed in our previous work (Chen et. al, 2024) offers a structured yet flexible framework that tailors learning experiences to individual student needs, leveraging adaptive technologies and active learning strategies to foster deeper understanding and skill development. This approach aligns closely with both the TPACK and GenAI Competence Frameworks, ensuring the pedagogical use of GenAI tools is thoughtfully integrated and responsive to diverse learner needs.

Implementation Strategy

The successful adoption of the GenAI Competence Framework extends beyond curriculum updates and pedagogical innovation. It requires a comprehensive implementation strategy that addresses the diverse needs of different stakeholders within the education ecosystem. This implementation strategy includes educator capacity-building, curriculum integration, extra-curricular support, mentorship programmes, and strong collaboration with industry.

Staff Capacity-Building

Educators play a critical role in the successful implementation of the GenAI Competence Framework. Comprehensive upskilling initiatives will equip educators with the knowledge, skills, and tools necessary to integrate GenAI effectively into their teaching practices. These initiatives will be complemented by the development of dedicated resources, including case studies, best practices and guidance on AI integration, ensuring educators are well-equipped to integrate GenAI effectively into their modules where appropriate. Working groups consisting of relevant Module Organisers, Programme Directors etc. will be formed in order to train staff and support them through the integration of GenAI in the teaching and assessment within their modules. A series of targeted workshops will focus on reflecting on the practices deployed within several modules in the initial phase and set out plans for the next phase. These will include effective teaching delivery techniques and authentic and feasible assessment strategies built in line with the GenAI Competency Framework.

Curriculum Integration

The framework adopts a staged approach to embedding GenAI into the curriculum, as outlined in the previous section. This progression enables students to build foundational GenAI literacy early in their studies and advance to specialised and domain-specific competencies in their later years. Curriculum integration must align with degree programme learning outcomes and accreditation standards to ensure coherence and relevance. Adequate time and resources, including access to GenAI tools, will be secured to facilitate a smooth and effective transition.

Extra-Curricular Support

As not all students have the same level of exposure to GenAI tools before they join the university and not all learners possess the same level of awareness and skills for interacting with GenAI tools, tailored extra-curricular support is essential. Workshops and hands-on sessions will be designed to provide practical exposure to GenAI applications in learning. These initiatives will address the diverse needs of students, bridging the digital divide and promoting inclusivity and accessibility. By offering tailored opportunities for skill development, extra-curricular support ensures that all learners, regardless of their prior experience, can effectively engage with and benefit from GenAI tools in their learning.

Mentorship and Peer Learning

The framework recognises the importance of collaboration and peer-driven learning. Structured mentorship programmes will enable GenAI-knowledgeable students to act as ambassadors, guiding their peers in practical applications. This approach not only reinforces learning but also fosters a sense of community and shared growth among students.

Industry Collaboration

Ongoing engagement with industry partners is a critical component of the implementation strategy. The framework will be regularly reviewed in consultation with the university's Industry Advisory Board (IAB) to ensure alignment with evolving technologies and workplace demands. Additionally, guest lectures by AI professionals will be organised to provide students with insights into cutting-edge developments and real-world applications of GenAI, bridging the gap between academic learning and industry practice.

Evaluation and Impact Assessment

Evaluation and impact assessment is a critical component of the GenAI Competence Framework, ensuring its effective implementation in achieving the desired educational goals, expected learning outcomes, and alignment with industry standards while maintaining adaptability to technological advancements. Drawing inspiration from the Academic eValuation Matrix (AVM) proposed by Shailendra et. al (2024), the framework employs a multi-dimensional approach to measure its impact. This approach focuses on key stakeholders, including students, educators, curriculum design, and the broader institutional and professional contexts. Table 1 summarises the evaluation metrics across these dimensions, reinforcing the framework's methodological rigour and its capacity for continuous improvement.

Specific evaluation methods are mapped to various focus areas within each dimension, enabling a comprehensive and holistic assessment of the framework's effectiveness. This ensures that the GenAI Competence Framework not only delivers measurable value but also supports student success and aligns with academic and professional standards in an increasingly dynamic technological landscape.

Table 1

Evaluation and Impact Assessment Methods

Assessment Dimension	**Key Focus Areas**	**Evaluation Methods**
Student Outcomes	Competency Development	Formative and summative evaluations through project work, problem-solving exercises, and capstone projects.
	Graduate Readiness	Tracer studies and alumni feedback to assess preparedness for AI-integrated workplaces and alignment with employer needs.

	Inclusivity and Accessibility	Surveys and focus groups to understand students' perceptions of inclusivity and support for diverse GenAI exposure levels.
Educator Engagement and Effectiveness	Skill Development	Pre- and post-training evaluations to measure improvements in educators' ability to teach and integrate GenAI effectively.
	Teaching Innovation	Faculty feedback to evaluate the impact of GenAI integration on teaching practices, curriculum design, and student engagement.
	Sustainability of Adoption	Metrics to assess the long-term feasibility and resource requirements of GenAI integration into teaching practices.
Curriculum Alignment with Technology advancements	Alignment with Programme Goals	Periodic reviews to ensure alignment with accreditation body guidelines and programme learning outcomes.
	Assessment Integrity	Evaluations of redesigned assessments to prevent misuse of GenAI tools while fostering creativity and innovation.
	Integration Metrics	Monitoring of scaffolded learning progression across foundational, technical, and domain-specific competencies.
Institutional Alignment and Industry Relevance	Stakeholder Feedback	Engagement with industry partners and accreditation bodies to validate the framework's relevance and rigour.
	Technological Adaptation	Benchmarking against emerging GenAI tools and technologies to maintain relevance in a rapidly evolving landscape, while closely monitoring global AI policy changes to ensure compliance with regulatory and ethical AI standards.
	Industry Partnerships	Assessment of collaborative activities such as guest lectures and joint projects for real-world exposure.

Sustainability Roadmap

To ensure the ongoing relevance and adaptability of the GenAI Competence Framework, a structured sustainability strategy is essential. The framework will undergo an annual review led by a dedicated Curriculum Review Committee, comprising academic staff, industry partners, and student representatives. This committee will evaluate stakeholder feedback, monitor developments in AI technologies, and revise the competence tiers, curriculum content, and pedagogical approaches as needed. The framework will also be benchmarked regularly against evolving industry standards and international AI literacy frameworks to maintain its rigour and alignment with real-world expectations. As illustrated in Figure 1, the framework consists of four interconnected components that form a closed loop, allowing insights from evaluation and impact assessments to drive iterative updates. Regular reviews of students' and staff's GenAI capabilities, coupled with monitoring of technological advancements, and industry expectations, will inform gap analyses and guide timely curriculum adjustments.. For instance, the GenAI skills of incoming student cohorts may vary significantly, and changes in policies regarding GenAI literacy at the school level could influence how universities tailor their efforts to develop GenAI competence.

Given the rapid pace of AI advancements, fostering a culture of continuous learning and adaptability is vital. At the same time, the framework emphasises the importance of human-centred learning, ensuring that GenAI complements rather than replaces the interpersonal relationships central to effective education. Maintaining meaningful educator-student interactions will preserve the core educational values while preparing graduates for AI-integrated professional environments.

Institutional commitment plays a critical role in sustaining the framework. Ongoing investment in staff training, digital infrastructure, and learning resources is essential for long-term success. Institutional support not only provides the necessary resources for implementation but also strengthens the framework's flexibility and resilience in the face of rapid technological change.

While institutions may encounter financial and technical barriers to GenAI integration, these challenges can be mitigated through a phased implementation strategy. Rather than pursuing full-scale adoption from the outset, institutions can begin with pilot modules, allowing gradual expansion based on lessons learned. Open-source GenAI tools and cloud-based platforms with free or low-cost educational licences offer cost-effective options. In addition, national and international funding schemes focused on digital transformation in education can provide further support.

Collaborative strategies also enhance sustainability. Cross-institutional partnerships enable the sharing of best practices, co-development of teaching materials, and joint staff training initiatives. Furthermore, integrating GenAI into existing digital literacy and coding programmes can streamline implementation by building on established curricula. This approach is particularly valuable for institutions operating in resource-constrained environments, as it promotes GenAI competence development without the need for entirely new course structures.

Conclusion

The GenAI Competence Framework presented in this paper provides a coherent, structured and practical approach to embedding GenAI competence development within Engineering education. Distinct from existing AI literacy models, this framework provides a holistic strategy with clear actionable guidelines that integrate GenAI competence directly into the curriculum. Through its four interlinked elements: structured competence tiers, curriculum integration strategies, practical implementation plans, and impact assessment mechanisms, the framework establishes a closed-loop structure designed for self-assessment and continuous improvement, ensuring its ongoing responsiveness to technological advancements and evolving stakeholder expectations.

By systematically embedding GenAI development into both technical and skill-based modules, the framework bridges the gap between AI education and real-world workforce requirements, preparing graduates to collaborate effectively with AI in professional contexts. Emphasising beyond technical proficiency, the framework explicitly cultivates an understanding of ethical, legal, regulatory, and societal considerations, encouraging students to critically engage with the question of not only what AI can do, but more importantly, what AI should do. This deliberate ethical focus ensures that future engineers are equipped to make responsible and human-centred decisions when developing and applying GenAI technologies.

Another key strength of the framework lies in its structured impact assessment methodology, which fosters an embedded mechanism for reflective practice and iterative refinement. This adaptability positions the framework as a scalable and transferable model, offering potential applicability beyond Engineering into other disciplines where AI-driven innovation is reshaping professional practice.

By addressing the dynamic and interdependent relationships among emerging technologies, academic curricula, ethical standards, and workforce demands, the proposed framework delivers a future-proof strategy for higher education institutions. It lays a robust and sustainable foundation for equipping students not only with critical GenAI competencies but also with the ethical mindset necessary to lead and innovate responsibly in AI-integrated workplaces.

Limitations and Future Work

While the GenAI Competence Framework provides a structured approach to embedding AI skills in Engineering education, certain challenges must be addressed to maximise its effectiveness.

One primary is the rapid evolution of GenAI technologies, which demands frequent reviews and updates to curriculum content and teaching methodologies. While the framework includes mechanisms for continuous improvement, sustaining long-term relevance demands ongoing collaboration between academia, industry, and accreditation bodies.

Additionally, the framework's initial focus is on Engineering disciplines, leveraging existing AI-related modules. Expanding its application to other fields, such as healthcare, business, and the humanities, will require customisation to align with disciplinary needs. For example, the tiered GenAI competence model could be tailored for Health Sciences by aligning foundational GenAI skills with ethical considerations in patient data, while Tier 3 would address domain-specific applications such as clinical decision support systems. Future research should explore interdisciplinary adaptations, ensuring that GenAI competence is effectively embedded across diverse academic and professional contexts.

Another challenge lies in evaluating the long-term impact of the framework. Future work will involve pilot testing within selected engineering modules to assess student outcomes, gather educator feedback, and ensure curriculum alignment. These pilot studies will provide empirical grounding to support broader institutional adoption. Ongoing efforts will also include tracking alumni engagement, employer feedback, and real-world AI application trends to refine the framework and ensure its continued relevance. Inclusivity and accessibility will remain central to future iterations of the framework. Efforts will focus on exploring flexible learning pathways to ensure equitable opportunities for all students, regardless of their backgrounds or circumstances.

By addressing these challenges and continuously refining its core components, the GenAI Competence Framework will continue to evolve as a dynamic and adaptable model, driving innovation in Engineering education and preparing students to thrive in a human-AI collaborative society within an ever-evolving technological landscape.

Acknowledgements

The authors declare no conflicts of interest and confirm that no funding was received for this manuscript beyond the allocation of academic time by the university. This work was fully supported by the university, and the proposed framework was approved by the institutional Academic Committee.

AI Usage Disclaimer

This study utilized the generative AI tool ChatGPT-4 for revision and editorial purposes during manuscript preparation. All outputs generated by the tool were reviewed, edited, and approved by the authors, who take full responsibility for the final content of this work.

References

Anderson, L. W., & Krathwohl, D. R. (2001). A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives. New York: Longman. ISBN: 978-0801319037

Bozkurt, A. ed. (2024). Why generative AI literacy, why now and why it matters in the educational landscape?: Kings, queens and GenAI dragons. *Open Praxis, 16(3)*, pp.283-290. Available at: https://openpraxis.org/articles/739/files/66d07b470f51b.pdf (Accessed: December 2024).

Brande, L., Carretero, S., Vuorikari, R., et al. (2016) DigComp 2.0: the digital competence framework for citizens. *European Commission, Joint Research Centre*. Publications Office. https://data.europa.eu/doi/10.2791/11517 (Accessed: December 2024).

Carretero, S., Vuorikari, R., and Punie, Y. (2017) DigComp 2.1: the digital competence framework for citizens with eight proficiency levels and examples of use. *European Commission, Joint Research Centre.* Publications Office. https://data.europa.eu/doi/10.2760/38842 (Accessed: December 2024).

Cha, Y., Dai, Y., Lin, Z., Liu, A. and Lim, C.P. (2024). Empowering university educators to support generative AI-enabled learning: Proposing a competency framework. *Procedia CIRP, 128,* pp.256-261. https://doi.org/10.1016/j.procir.2024.06.021

Chen, Y., Chai, K.K., Ma, L., Liu, C., Zhang, T. (2024). Empowering University Students with A Guided Personalised Learning Model. *2024 IEEE Global Engineering Education Conference (EDUCON)*, Kos Island, Greece, 2024, pp. 1-4, doi: 10.1109/EDUCON60312.2024.10578616. https://doi.org/10.1109/EDUCON60312.2024.10578616

Floridi, L., Cowls, J., Beltrametti, M. et al. (2018). *AI4People—An Ethical Framework for a Good AI Society*. Minds and Machines, 28(4), 689–707. https://doi.org/10.1007/s11023-018-9482-5

García-Peñalvo, F. and Vázquez-Ingelmo, A. (2023). What do we mean by GenAI? A systematic mapping of the evolution, trends, and techniques involved in Generative AI. *International*

Journal of Interactive Multimedia and Artificial Intelligence, p7-16, 2023. Available at https://www.ijimai.org/journal/sites/default/files/2023-11/ijimai8_4_1.pdf (Accessed: December 2024).

Hill, P.A., Narine, L.K. and Miller, A.L. (2024). Prompt engineering principles for generative AI use in extension. *The Journal of Extension*, *62*(3), p.20.

International Society for Technology in Education, n.d., *ISTE standards*. Available at: https://iste.org/standards (Accessed: November 2024).

Kamalov, F., Santandreu Calonge, D., & Gurrib, I. (2023). New era of artificial intelligence in education: Towards a sustainable multifaceted revolution. *Sustainability*, *15*(16), 12451. *https://doi.org/10.3390/su151612451.*

Kim, S.-K., Kim, T.-Y., & Kim, K. (2025). Development and effectiveness verification of AI education datasets based on constructivist learning principles for enhancing AI literacy. *Scientific Reports, 15*, Article 10725. https://doi.org/10.1038/s41598-025-95802-4

Mehrabi, N., Morstatter, F., Saxena, N., Lerman, K., & Galstyan, A. (2021). *A Survey on Bias and Fairness in Machine Learning*. ACM Computing Surveys, 54(6), 1–35. https://doi.org/10.1145/3457607

Mishra, P., & Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A new framework for teacher knowledge. *Teachers College Record* 108 (6), 1017-1054

Ministry of Communications and Information. (2018). *Digital readiness blueprint*. Singapore: Ministry of Communications and Information. Available at: https://www.mddi.gov.sg/files/dr%20blueprint.pdf (Accessed: November 2024).

National Literacy Trust, n.d., *What is literacy?*. Available at: https://literacytrust.org.uk/information/what-is-literacy/ (Accessed: November 2024)

Ng, D. T. K., Leung, J. K. L., Chu, S. K. W. and Qiao, M. S. (2021). Conceptualising AI literacy: an exploratory review. *Computers and Education: Artificial Intelligence*, 2, p.100041. Available at: https://doi.org/10.1016/j.caeai.2021.100041

Ng, D.T.K., Leung, J.K.L., Su, J. et al. (2023). Teachers' AI digital competencies and twenty-first century skills in the post-pandemic world. *Education Tech Research Dev 71*, 137–161. https://doi.org/10.1007/s11423-023-10203-6

OECD. (2023). OECD Digital Education Outlook 2023: Towards an Effective Digital Education Ecosystem. *OECD Publishing, Paris*, Available at https://doi.org/10.1787/c74f03de-en

Özden, M., Örge Yaşar, F., & Meydan, E. (2025). The relationship between pre-service teachers' attitude towards artificial intelligence (AI) and their AI literacy. *Pegem Journal of Education and Instruction, 15*(3), 121–131. https://doi.org/10.47750/pegegog.15.03.13

QAA. (2023). Subject Benchmark Statement: Engineering. *QAA*. Available at: https://www.qaa.ac.uk/docs/qaa/sbs/sbs-engineering-23.pdf?sfvrsn=7c71a881_4 (Accessed: December 2024).

Rashid, A. B., & Kausik, A. K. (2024). AI revolutionizing industries worldwide: A comprehensive overview of its diverse applications. *Hybrid Advances*, 100277. https://doi.org/10.1016/j.hybadv.2024.100277

Reddy, P., Sharma, B. and Chaudhary, K. (2020). Digital literacy: A review of literature. *International Journal of Technoethics (IJT)*, *11*(2), pp.65-94. https://doi.org/10.4018/IJT.20200701.oa1

Shailendra, S., Kadel, R. and Sharma, A. (2024). Framework for Adoption of Generative Artificial Intelligence (GenAI) in Education*. IEEE Transactions on Education*. vol. 67, no. 5, pp. 777-785, Oct. 2024, https://doi.org/10.1109/TE.2024.3432101

Southworth, J., Migliaccio, K., Glover, J., Glover, J., Reed, D., McCarty, C., Brendemuhl, J. and Thomas, A. (2023) 'Developing a model for AI Across the curriculum: transforming the higher education landscape via innovation in AI literacy', *Computers and Education: Artificial Intelligence*, 4, p.100127. https://doi.org/10.1016/j.caeai.2023.100127

THIGA, M.M. (2024). Generative AI and the Development of Critical Thinking Skills. *IRE Journal*, Volume 7 Issue 9. Available at: https://www.irejournals.com/formatedpaper/1705580.pdf (Accessed: December 2024).

Tzirides, A. O., Zapata, G., Kastania, N. P., Saini, A. K., Castro, V., Ismael, S. A., You, Y., dos Santos, T. A., Searsmith, D., O'Brien, C., Cope, B., & Kalantzis, M. (2024). Combining human and artificial intelligence for enhanced AI literacy in higher education. *Computers and Education Open, 6*, 100184. https://doi.org/10.1016/j.caeo.2024.100184

UNESCO. (2023). Guidance for Generative AI in Education and Research. *United Nations Educational, Scientific and Cultural Organization (UNESCO): Paris, France.* https://doi.org/10.54675/EWZM9535 (Accessed: December 2024).

Voigt, P. & Von dem Bussche, A. (2017). *The EU General Data Protection Regulation (GDPR): A Practical Guide*. Springer International Publishing.

World Economic Forum. (2024). Shaping the Future of Learning: The Role of AI in Education 4.0. Available at https://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Learning_2024.pdf (Accessed: December 2024).Wut, T.M., Chan, E.A.-h., Wong, H.S.-m. and Chan, J.K.Y. (2025), Perceived artificial intelligence literacy and employability of university students, *Education + Training*, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/ET-06-2024-0272

Zhou, X. and Schofield, L. (2024). Developing a conceptual framework for Artificial Intelligence (AI) literacy in higher education. *Journal of Learning Development in Higher Education*, (31). https://doi.org/10.47408/jldhe.vi31.1354