A Systematic Literature Review on the Role of Engineering Education in an Evolving Educational Landscape

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ABSTRACT

This systematic literature review (SLR) examines the evolving role of engineering education in the face of rapid technological disruption, shifting industry demands, and societal expectations for sustainability. Drawing on 2019–2025 literature, four converging themes are identified: (1) digital and online learning, (2) industry–academia collaboration, (3) future-ready competencies, and (4) sustainability and ethics. Digital platforms such as Massive Open Online Course (MOOCs), flipped classrooms, and AI-driven tools are transforming pedagogy, while collaborations with industry enhance authentic problem-solving and employability. At the same time, new competency frameworks emphasise interdisciplinary skills, adaptability, and AI literacy. Sustainability and ethics are increasingly embedded into curricula, yet inconsistently operationalised. Persistent challenges include faculty readiness, unequal digital access, and limited assessment tools for complex competencies. This review highlights best practices and gaps, concluding with recommendations for integrated curriculum design, stronger policy support, and robust measurement frameworks. It argues for a holistic, adaptive model of engineering education capable of preparing graduates as technologically proficient, socially responsible, and globally adaptable professionals.

Keywords: Digital learning, engineering education, industry-academia collaboration, skills and competency, sustainability and ethics

1. INTRODUCTION

Engineering education is undergoing a huge transformation driven by rapid technological advancement, evolving industry expectations, and increasing societal emphasis on sustainability and ethical responsibility. Traditional teaching models centred on lectures and content transmission are being reshaped by digital platforms, immersive technologies, and data-informed pedagogies. Concurrently, employers demand graduates who combine technical expertise with adaptability, creativity, and social consciousness, attributes essential for the human–technology partnership envisioned under Industry 5.0.

While earlier studies have examined specific aspect such as online learning, competency-based education, or ethics integration, few have explored their interconnections in a unified framework. This review responds to that gap by offering an integrative synthesis of four converging domains, namely, (i) digital learning, (ii) industry–academia collaboration, (iii) future-oriented competencies, and (iv) sustainability and ethics in engineering education. The review's novelty lies in mapping these interrelated trends to provide a holistic understanding of how they collectively redefine the educational landscape for engineers in the 21st century.

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The focus on literature from 2019 to 2025 captures post-pandemic shifts and the emergence of AI-enhanced learning environments, areas still underrepresented in current reviews. By analysing peer-reviewed studies across global contexts, this paper highlights both progress and persisting barriers in aligning curricula with technological and societal needs. It thereby contributes empirical and conceptual insights for curriculum reform, institutional planning, and policy formulation.

The research questions guiding this review are as follows:
1. What dominant trends are shaping the transformation of engineering education?
2. How effectively have emerging technologies and pedagogies been integrated?
3. What challenges hinder the alignment between academia and industry?
4. What best practices and future directions can guide sustainable educational reform?

Overall, this study advances the discourse on engineering education by proposing a holistic, evidence-based framework that integrates technological, industrial, ethical, and humanistic dimensions. Such synthesis is vital to ensure that future engineers are not only technologically proficient but also socially responsible and globally adaptable professionals

2. METHODOLOGY

2.1 Search Strategy

A systematic literature search was conducted using IEEE Xplore, Scopus, Web of Science, ScienceDirect, ERIC, and Google Scholar, which collectively cover engineering education, technology adoption, and higher education research. Keywords included *"engineering education"*, *"educational transformation"*, *"Industry 4.0/5.0 and education"*, *"online learning"*, *"competency-based learning"*, *"sustainability"*, and *"ethics"*. Boolean operators were applied (e.g., "engineering education" AND ("future trends" OR "evolving landscape")) to refine results. The review focused on 2015–2024 publications, with emphasis on the post-pandemic period (2019–2025) to capture the rise of AI, hybrid pedagogy, and new competency frameworks.

2.2 Inclusion and Exclusion Criteria

Selection of the articles followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, as illustrated in Figure 1.
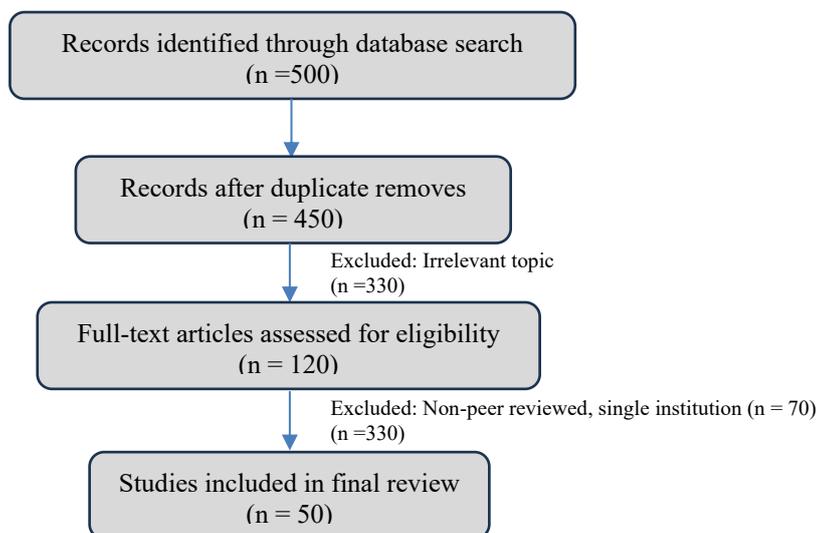

Figure 1. PRISMA flow diagram for the study.

Only peer-reviewed journal papers and conference proceedings were considered to ensure scholarly reliability. The selected studies specifically addressed themes of engineering education reform, technological integration, competency development, or sustainability and ethics, and included empirical research, case analyses, or systematic reviews. Opinion pieces, non-reviewed materials, and studies confined to a single institutional context without broader relevance were excluded as in Table 1. Likewise, works unrelated to engineering education were omitted to maintain thematic focus and analytical consistency.

Table 1 Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Timeframe	2015–2024	<2015 unless seminal
Type	Peer-reviewed journals & conferences	Opinion pieces, non-peer-reviewed
Focus	Reform, technology, competencies, ethics/sustainability	Single-institution only, irrelevant focus

2.3 Screening and Data Extraction

The screening process comprised three systematic phases. First, titles and abstracts were reviewed to exclude studies outside the review's scope. Next, the remaining articles underwent full-text evaluation to ensure compliance with the inclusion criteria. Finally, data from the selected studies were extracted and thematically coded under four dimensions of digital learning, industry–academia collaboration, future-ready competencies, and sustainability with ethics. This process ensured methodological rigor and consistency across the reviewed literature.

2.4 Data Synthesis

Extracted data were subjected to thematic analysis, allowing the identification of recurring patterns, best practices, and research gaps. The synthesis emphasized cross-linkages among the four domains to generate a cohesive understanding of how engineering education is adapting to digitalization, industry transformation, and global sustainability imperative.

3. FINDINGS AND DISCUSSION

This review identifies four interrelated themes that collectively define the ongoing transformation of engineering education. These themes encompass digital learning, industry–academia collaboration, future-ready competencies, and the integration of sustainability and ethics. Together, they illustrate how technological advancement, industrial engagement, and social responsibility are converging to shape a more adaptive and holistic educational framework for engineers.

3.1 Digital Learning and Online Education

Digital transformation has fundamentally altered teaching and learning in engineering. The adoption of MOOCs, flipped classrooms, and AI-supported learning systems has expanded access and flexibility while personalising learning experiences. Recent studies confirm that simulation-based and adaptive environments improve student engagement, conceptual understanding, and retention [9–12].

Innovations such as 360° virtual field trips, remote laboratories, and AI-driven tutoring provide authentic learning contexts that emulate industrial and field environments. For example, 360° virtual field trips have improved spatial reasoning in geoscience and civil engineering courses,

while remote labs enable students to operate real equipment online with comparable learning outcomes to traditional labs.

Despite these advances, implementation remains uneven. Institutions face challenges including high infrastructure costs, insufficient digital literacy among faculty, and lack of pedagogical frameworks for integrating AI ethically and effectively.

Table 2 Emerging practices in digital engineering education

Innovation	Pedagogical Benefit	Limitation
MOOCs & flipped classrooms	Flexible access, active learning	Quality assurance, engagement consistency
Remote & virtual labs	Realistic experimentation, scalability	Cost, technical support
AI-adaptive learning	Personalisation, real-time feedback	Data privacy, algorithmic bias

3.2 Industry–Academia Collaboration

Strengthening collaboration between universities and industry is vital for aligning curricula with professional practice. Effective models include co-supervised capstone projects, embedded certification schemes, and industrial centres of excellence (ICoEs). In Malaysia, ICoEs at UTM and UPM have enhanced employability through joint supervision and competency-based training [13–17]. Similarly, partnerships integrating digital manufacturing or sustainable energy certifications ensure graduates acquire industry-relevant credentials prior to employment.

These collaborations foster experiential learning and innovation capacity. However, sustaining them requires mutual commitment, clear governance, and equitable resource sharing. Without such structures, partnerships risk becoming symbolic rather than transformative.

3.3 Future-Ready Competencies

Engineering education is transitioning from knowledge transmission to competency-based and project-oriented learning. The emphasis has shifted toward demonstrable outcomes such as problem-solving, interdisciplinary collaboration, and AI literacy.

Notable initiatives include micro-credential frameworks that allow learners to stack verified skills toward formal qualifications [29–31]. Multi-course project-based learning (PBL) models, as implemented in Qatar and Australia, show measurable improvements in critical thinking and design integration. Furthermore, inclusive upskilling programs, like RMIT's online diploma for women in technology and illustrate how competency-based education supports diversity and lifelong learning.

Despite positive outcomes, challenges remain in aligning assessment systems with outcome-based accreditation and maintaining depth of learning within modular formats. Institutions must balance flexibility with academic rigour to ensure competence development remains comprehensive and measurable.

3.4 Sustainability and Ethics in Engineering Education

The infusion of sustainability and ethics into engineering curricula reflects a global recognition of engineers' responsibility toward society and the environment. Frameworks linking the Sustainable Development Goals (SDGs) with engineering design, along with initiatives grounded

in Islamic and universal ethical principles, demonstrate innovative pedagogical directions [36–38].

However, integration often remains superficial, appearing as elective topics or isolated modules rather than core curricular outcomes. Lozano et al. [36] emphasised that sustainability education requires explicit learning outcomes, authentic assessment, and alignment with disciplinary content. Integrating ethical reasoning into design-based learning, as evidenced in initiatives reported by Ferdman and Ratti [37], reflects a global movement toward uniting technical excellence with moral accountability.

To institutionalise these values, universities must provide faculty training, cross-disciplinary collaboration, and assessment tools capable of measuring ethical reasoning and sustainable design competencies.

3.5 Cross-Cutting Challenges

Despite considerable innovation, several structural challenges continue to impede progress across all domains of engineering education. Rapid advancements in artificial intelligence and automation require continuous curriculum renewal and systematic faculty upskilling to maintain technological relevance [32–33]. At the same time, unequal access to digital infrastructure and reliable connectivity perpetuates learning disparities, particularly in developing regions [34–35]. Many educators also remain insufficiently prepared for contemporary pedagogical models such as adaptive learning and competency-based assessment. Furthermore, the absence of validated instruments for evaluating complex attributes, including ethical reasoning, sustainability awareness, and interdisciplinary collaboration, limits the measurement of educational outcomes. Addressing these issues demands comprehensive reform supported by coherent policies, sustained industry partnerships, and institutional investment in both digital and human capital.

4. FUTURE DIRECTIONS

As the demands placed upon engineers become increasingly complex and global, engineering education must evolve toward models that are adaptive, interdisciplinary, and ethically grounded. This review highlights three future directions that are shaping the trajectory of the discipline, namely: (1) interdisciplinary and systems-based learning, (2) AI-driven personalised education, and (3) global and cultural adaptability.

4.1 Interdisciplinary and Systems-Based Learning

Engineering challenges, ranging from climate adaptation to digital transformation, require solutions that integrate knowledge across multiple domains. Universities are thus shifting from siloed disciplinary approaches toward interdisciplinary project-based learning (iPBL) models that merge engineering, social sciences, and design thinking.

The MIT NEET (New Engineering Education Transformation) program exemplifies this trend by structuring curricula around thematic "threads" (as energy, mobility, or living systems) that combine mechanical, electrical, and biological principles [39]. Students exposed to iPBL environments demonstrate stronger innovation capacity, systems thinking, and problem contextualisation [40].

However, institutional barriers, such as rigid accreditation requirements and compartmentalised faculty expertise are continue to impede widespread adoption. To overcome these, universities should develop flexible curricular architectures that allow cross-departmental collaboration while maintaining core engineering rigour.

4.2 AI-Driven and Data-Informed Personalised Learning

Artificial intelligence is redefining how learning is delivered, assessed, and optimised. AI-driven adaptive platforms can analyse learners' performance in real time, adjust content sequencing, and provide personalised feedback loops. Merino [25] reported significant gains in student engagement and achievement within AI-supported engineering MOOCs.

Beyond adaptation, AI also enables learning analytics that inform curriculum design, identifying systemic weaknesses and predicting student performance trends. Yet, this transformation must be guided by ethical safeguards, ensuring algorithmic transparency, data protection, and avoidance of bias [41].

Future research should therefore focus on the development of AI ethics frameworks specific to educational contexts and explore how human–AI collaboration can enhance, rather than replace, the mentoring role of educators.

4.3 Globalisation and Cultural Adaptability

Modern engineering practice is inherently global. Engineers must collaborate across cultures, navigate diverse regulatory contexts, and design solutions for varied socio-environmental settings. Consequently, global mobility programs, virtual international projects, and culturally contextualised curricula are becoming central to professional formation.

Programs such as the Global Engineering Education Exchange (GE3) and Aalborg University's international PBL framework have demonstrated how cross-border collaboration enhances intercultural competence and reflective practice [42]. Malaysian universities including IIUM and have incorporated SDGs and interdisciplinary design elements into capstone projects, promoting both global citizenship and local relevance.

To institutionalise such initiatives, universities must embed intercultural communication, global ethics, and sustainability frameworks into their program outcomes. This will cultivate graduates who are not only technically competent but also capable of designing equitable and inclusive solutions in diverse contexts.

4.4 Toward an Integrated Educational Paradigm

The future of engineering education lies in its ability to balance technological proficiency with humanistic purpose. Interdisciplinary learning builds cognitive flexibility; AI personalisation enhances inclusivity and engagement; and global adaptability fosters ethical and culturally sensitive practice.

Together, these trends point toward a holistic educational paradigm, that integrates cognitive, affective, and ethical competencies to prepare engineers as innovators, collaborators, and stewards of sustainable development. Institutional reform, continuous faculty development, and supportive policy frameworks are essential to realise this transformation at scale.

5. CONCLUSION

Engineering education is rapidly transforming under the influence of digitalisation, industrial innovation, and global sustainability imperatives. This review synthesised four converging dimensions covering digital learning, industry–academia collaboration, future-ready competencies, and sustainability with ethics, revealing how they collectively redefine modern engineering pedagogy. Digital and AI-enhanced tools expand flexibility and personalisation, while

collaboration with industry strengthens authenticity and employability. Competency-based frameworks encourage adaptability and lifelong learning, and the integration of sustainability and ethics fosters social responsibility. Yet, persistent gaps remain in equitable access, faculty preparedness, and assessment of complex skills.

A coherent reform agenda is therefore essential to align pedagogy, policy, and professional practice. The future of engineering education must embrace an integrated, value-driven model that balances technological proficiency with ethical and humanitarian purpose, preparing engineers to innovate responsibly and contribute to a sustainable, resilient society. This review aligns with the vision of the ICESCO Chair in Sustainable Engineering, which advocates the integration of ethics and sustainability into engineering education to nurture socially responsible and future-ready professionals.

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