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Engineering Education, Research and Skills for Future Development

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Abstract-* *Engineering education stands at a critical juncture, facing unprecedented challenges from rapid technological advancement, environmental imperatives, and shifting societal expectations. This paper examines the evolving landscape of engineering education, research, and skills development required to prepare engineers for future challenges. Through a comprehensive literature review and quantitative analysis, the study investigates the alignment between current engineering curricula and the competencies demanded by emerging technologies and sustainable development goals. The research employed a quantitative survey methodology, collecting data from 187 engineering educators, industry professionals, and recent graduates across multiple institutions. Findings reveal significant gaps between academic preparation and industry requirements, particularly in areas of digital fluency, sustainability competencies, interdisciplinary collaboration, and professional skills development. The study identifies that while technical fundamentals remain essential, there is growing recognition of the need for broader competencies including systems thinking, ethical reasoning, and adaptive expertise. Results indicate that experiential learning approaches, industry-academia partnerships, and curriculum reform are critical for bridging identified gaps. The paper concludes with recommendations for transforming engineering education through integrated curriculum design, enhanced research-practice connections, and policy support for skills development. These findings have significant implications for educators, policymakers, and industry stakeholders seeking to develop engineering talent capable of addressing complex global challenges.

Keywords: Engineering Education, Skills Development, Curriculum Reform, Industry-Academia Collaboration, Sustainability Competencies.

I. INTRODUCTION

Engineering education serves as the foundation for developing the technical workforce essential for economic prosperity, technological innovation, and societal progress. The demands placed upon engineers have never been greater, as the world confronts interconnected challenges including climate change, digital disruption, infrastructure renewal, and the pursuit of more equitable and sustainable societies (Royal Academy of Engineering, 2025). These challenges require engineers with not only strong technical foundations but also broader competencies including systems thinking, ethical reasoning, interdisciplinary collaboration, and adaptive expertise. The rapid advancement of artificial intelligence, autonomous systems, and digital technologies further transforms the engineering landscape, demanding new skills and knowledge frameworks (Ahmad et al., 2026).

Contemporary engineering education faces persistent challenges in preparing graduates for the evolving demands of professional practice. Research indicates that while technical fundamentals remain essential, there is a growing recognition of the need for broader competencies including communication, teamwork, problem-solving, leadership, and project management skills (Chadha and Heng, 2024). However, significant gaps persist between academic preparation and industry requirements, with employers frequently expressing concerns about graduates' readiness for professional practice (Lal et al., 2025). These gaps are particularly pronounced in areas of digital fluency, sustainability competencies, and interdisciplinary collaboration, which have become increasingly critical in modern engineering practice.

The Engineers 2030 project, led by the Royal Academy of Engineering on behalf of the National Engineering Policy Centre, represents a comprehensive effort to rethink engineering education and skills for a sustainable and inclusive future (Royal Academy of Engineering, 2025). The project's final report, published in 2025, outlines ten recommendations for catalytic changes to develop an engineering education and skills system fit for purpose. The report emphasizes the need for resilient and future-facing education, socially responsible and inclusive approaches, data and digital fluency, and commercial and economic literacy as essential principles guiding engineering education transformation (Royal Academy of Engineering, 2025).

This paper investigates the current state of engineering education, research, and skills development in the context of future challenges. The study examines the alignment between educational provision and industry needs, identifies critical gaps in current approaches, and proposes evidence-based recommendations for transforming engineering education. The research addresses the following questions: What competencies are required for future engineering practice? To what extent are current engineering curricula aligned with these requirements? What strategies are effective in developing the skills needed for future engineering practice?

II. LITERATURE REVIEW

A. Evolution of Engineering Education and Skills Requirements

The evolution of engineering education reflects changing societal needs, technological advancement, and professional expectations. Historically, engineering education emphasized technical fundamentals and analytical skills, with curricula focused on mathematics, science, and discipline-specific knowledge (Chadha and Heng, 2024). This traditional model assumed that professional skills would be developed through workplace experience following graduation. However, the complexity of contemporary engineering challenges has prompted reassessment of this approach, with growing recognition that professional skills development must be integrated throughout the educational process.

The National Academy of Engineering's Engineer of 2020 initiative identified key attributes required for future engineering practice, including strong analytical skills, practical ingenuity, creativity, good communication, business and management understanding, high ethical standards, dynamism, agility, resilience, and commitment to lifelong learning (Azemi & Khademi, 2025). Subsequent research has expanded and refined these competencies, recognizing the increasing importance of interdisciplinary knowledge, systems thinking, and contextual understanding (Lal et al., 2025). Ahmad et al. (2026) identified four converging themes in contemporary engineering education literature: digital and online learning, industry-academia collaboration, future-ready competencies, and sustainability and ethics. These themes reflect the multidimensional nature of engineering education transformation and the need for integrated approaches to curriculum development.

The Engineers 2030 Vision and Principles, developed through extensive stakeholder consultation, establish six guiding principles for engineering education: resilient and future-facing, socially responsible and inclusive, trusted by the public, integrated approach, data and digitally fluent, and commercially and economically literate (Royal Academy of Engineering, 2025). These principles emphasize the need for engineering education to prepare graduates who can navigate uncertainty, engage with diverse stakeholders, apply digital technologies effectively, and understand the economic and commercial context of engineering practice. The principles reflect a significant expansion of traditional engineering education objectives, acknowledging the broader capabilities required for effective professional practice in the twenty-first century.

B. Professional Skills Development in Engineering Education

Professional skills development has become increasingly central to engineering education discourse, with growing recognition that technical expertise alone is insufficient for effective professional practice. Chadha and Heng (2024) conducted a comprehensive scoping review of professional skills development in engineering education from 1980 to 2020, examining six specific skills: communication, teamwork, problem-solving,

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leadership, project management, and entrepreneurship. Their findings indicate that skills are more nuanced and accepted today than they were in 1980, with increased focus on specific skill areas and more sophisticated integrated delivery methods for teaching skills.

The importance of professional skills is underscored by employer expectations and accreditation requirements. Engineering accreditation bodies increasingly stipulate professional skills as essential requirements for accredited programs, reflecting the recognition that graduates must demonstrate both technical competence and professional capability (Chadha & Heng, 2024). However, implementation of professional skills development varies considerably across institutions and programs, with challenges including faculty expertise, resource constraints, and assessment difficulties. The development of these skills can seem highly unregulated and atomistic, depending on localised departmental interpretations of what it means for engineers to have professional skills.

Research indicates that effective professional skills development requires intentional curriculum design and pedagogical approaches that provide opportunities for practice and feedback. Active learning methods, including project-based and problem-based learning, have been shown to effectively develop professional skills alongside technical competencies (Lal et al., 2025). Experiential learning approaches, which engage students in authentic professional activities, are particularly effective in developing communication, teamwork, and problem-solving skills. However, institutional support and faculty development are essential for effective implementation of these approaches.

C. Digital Transformation and Engineering Education

The digital transformation of engineering practice has profound implications for engineering education, requiring graduates to be proficient in digital technologies and data-driven approaches. Ahmad et al. (2026) found that digital and online learning represents a major theme in contemporary engineering education literature, with digital platforms such as Massive Open Online Courses, flipped classrooms, and AI-driven tools transforming pedagogy. The COVID-19 pandemic accelerated adoption of digital learning approaches, with significant implications for engineering education delivery and assessment.

Data and digital fluency are identified as essential competencies for future engineering practice. The Engineers 2030 project emphasizes digital fluency as a key principle, recognizing that engineers must be able to apply digital technologies effectively and understand their implications for engineering practice (Royal Academy of Engineering, 2025). Research indicates that although 74 percent of engineering employers say advanced digital skills will be critical over the next three years, only 39 percent are currently prioritizing these for training (Engineering Council, 2025). This gap between perceived importance and current provision represents a significant challenge for engineering education.

Artificial intelligence and related technologies are transforming both engineering practice and education. Peixoto et al. (2025) examined the integration of sustainability into engineering education through AI-supported approaches, finding that practices such as circular economy, eco-design, and product-service systems combined with Industry 4.0 technologies promote development of curricula more aligned with sustainability. AI tools offer opportunities for life cycle analysis, simulations, and personalization of teaching, supporting more effective and contextualized engineering education. However, integration of these technologies requires faculty readiness, institutional support, and appropriate infrastructure.

D. Sustainability and Ethical Competencies

Sustainability emerged as a central concern in engineering education, reflecting the critical role of engineering in addressing environmental challenges and promoting sustainable development. Ahmad et al. (2026) found that sustainability and ethics are increasingly embedded into curricula, yet inconsistently operationalised across institutions and programs. Peixoto et al. (2025) noted significant growth in publications on sustainability in engineering education since 2020, highlighting the increasing recognition of sustainability as an essential competency for engineering graduates.

The integration of sustainability into engineering curricula requires attention to both knowledge and skills. Students must understand sustainability principles and their application to engineering practice, as well as develop skills in sustainable design, life cycle assessment, and environmental impact analysis. Ethical reasoning is also essential, as engineers must navigate complex trade-offs and stakeholder interests in sustainability contexts. Research indicates that experiential learning approaches, including project-based learning on sustainability challenges, are effective in developing these competencies.

Social responsibility and inclusivity are increasingly recognized as essential attributes of engineering practice. The Engineers 2030 principles emphasize social responsibility and inclusion, reflecting the expectation that engineers must consider the social implications of their work and engage with diverse communities (Royal Academy of Engineering, 2025). This requires attention to equity, diversity, and inclusion in engineering education, as well as development of skills in stakeholder engagement and community consultation.

E. Industry-Academia Collaboration and Curriculum Alignment

Industry-academia collaboration is essential for aligning engineering education with workforce needs and ensuring that graduates possess the competencies required for professional practice. Ahmad et al. (2026) identified industry-academia collaboration as a major theme in engineering education literature, finding that collaborations with industry enhance authentic problem-solving and employability. However, significant gaps persist between academic preparation and industry requirements, with employers frequently expressing concerns about graduates' readiness for professional practice.

Research indicates that stronger partnerships between universities and industry are essential for transforming engineering education. Azemi and Khademi (2025) emphasized the importance of a solid relationship with industry and society in engineering education, noting that this requires both curriculum development and program evaluation with focused learning assessment components. Effective industry-academia collaboration includes curriculum input from industry practitioners, work-integrated learning opportunities, and research partnerships that connect academic expertise with industry challenges.

The skills gap between education and industry is particularly pronounced in areas of emerging technologies and professional competencies. A systematized literature review by researchers found significant misalignment between university curricula, which emphasize STEM fundamentals, and industry requirements, which prioritise technical practice, interpersonal competencies, and meta-competencies such as adaptability, analytical thinking, and systems thinking (ASEE, 2026). Addressing this gap requires curriculum reform, enhanced industry engagement, and policy support for skills development.

III. MATERIALS AND METHODS

This study employed a quantitative research method to investigate the alignment between engineering education provision and industry requirements, and to identify effective strategies for developing competencies required for future engineering practice. The quantitative approach was selected to enable systematic measurement of variables, statistical analysis of relationships, and general findings that can inform policy and practice. The research design incorporated survey methodology, allowing collection of data from multiple stakeholder groups including engineering educators, industry professionals, and recent graduates.

The population for this study comprised engineering educators, industry professionals, and recent engineering graduates across multiple institutions and sectors. A stratified random sampling strategy was employed to ensure representation across engineering disciplines including civil, mechanical, electrical, chemical, and software engineering. The sample included 187 participants: 64 engineering educators from 12 universities, 73 industry professionals from 28 organizations across manufacturing, construction, technology, and consulting sectors, and 50 recent graduates who had completed their engineering degrees within the past three years. The sample size was determined based on power analysis to detect moderate effect sizes with adequate statistical power.

Data collection was conducted using an online survey instrument developed based on the literature review and validated through expert review and pilot testing. The survey comprised five sections: demographic information, perceptions of competency importance, assessment of current curriculum coverage, evaluation of teaching approaches, and identification of gaps and challenges. Competency items were derived from the Engineers 2030 principles and the broader engineering education literature, covering technical knowledge, professional skills, digital fluency, sustainability competencies, and interdisciplinary capabilities. Responses were measured using five-point Likert scales assessing perceived importance and current provision. The survey was distributed through professional networks, institutional mailing lists, and social media, with follow-up reminders to maximize response rates.

Data analysis employed descriptive statistics to characterize responses, inferential statistics including t-tests and ANOVA to examine group differences, and correlation analysis to explore relationships between variables. Statistical data were analyzed, with significance set at $p < .05$. Reliability analysis indicated good internal consistency for the survey scales, with Cronbach's alpha values ranging from .82 to .89. The research was conducted in accordance with ethical guidelines for research with human participants, including informed consent, confidentiality, and the right to withdraw.

IV. RESULTS AND DISCUSSION OF FINDINGS

F. Perceptions of Competency Importance

The study examined perceptions of competency importance across stakeholder groups, revealing significant agreement on the essential competencies for future engineering practice. Table 1 presents mean importance ratings for core competency areas, aggregated across all participants and by stakeholder group.

Table 1: *Mean Importance Ratings for Core Competency Areas by Stakeholder Group*

Competency Area	All Participants (N=187)	Educators (n=64)	Industry (n=73)	Graduates (n=50)	F-value	p-value
Technical Knowledge	4.72 (0.51)	4.81 (0.42)	4.68 (0.55)	4.66 (0.55)	1.48	.230
Problem Solving	4.83 (0.41)	4.88 (0.34)	4.82 (0.43)	4.78 (0.46)	0.82	.441
Communication	4.65 (0.58)	4.59 (0.63)	4.71 (0.51)	4.62 (0.61)	0.78	.461
Teamwork	4.59 (0.62)	4.53 (0.67)	4.66 (0.57)	4.56 (0.63)	0.76	.470
Digital Fluency	4.48 (0.69)	4.31 (0.73)	4.63 (0.61)	4.46 (0.70)	3.82	.024*
Sustainability	4.27 (0.78)	4.19 (0.79)	4.38 (0.75)	4.20 (0.82)	1.11	.332
Interdisciplinary	4.39 (0.71)	4.31 (0.73)	4.49 (0.68)	4.34 (0.73)	1.16	.315
Ethical Reasoning	4.52 (0.66)	4.48 (0.67)	4.58 (0.63)	4.48 (0.69)	0.47	.625
Leadership	4.21 (0.84)	4.09 (0.85)	4.33 (0.79)	4.18 (0.87)	1.38	.254
Project Management	4.34 (0.76)	4.22 (0.80)	4.48 (0.69)	4.28 (0.79)	2.13	.122

*Note: Values are mean (standard deviation). Ratings on 1-5 scale where 1 = not important, 5 = critically important. *$p < .05$ indicates significant difference between groups.*

Table 1 demonstrates that all competency areas were rated as important to critically important (means > 4.21), indicating broad agreement across stakeholder groups on the multidimensional nature of engineering competence. Problem solving (M=4.83, SD=0.41) received the highest importance rating, consistent with the centrality of problem-solving to engineering practice. Technical knowledge (M=4.72, SD=0.51) was also highly rated, confirming the continued importance of technical fundamentals despite emphasis on broader competencies.

The only significant difference between stakeholder groups was for digital fluency (F=3.82, p=.024), with industry professionals rating this competency significantly higher than educators. This finding is consistent with research indicating that employers see advanced digital skills as critical for future engineering roles, while educational institutions may be slower to integrate digital competencies into curricula (Engineering Council, 2025). The gap between industry and educator perceptions of digital fluency importance may contribute to the skills gap identified in other studies.

G. Gap Analysis between Curriculum Provision and Industry Requirements

A key objective of this study was to identify gaps between current curriculum provision and industry requirements. Table 2 presents gap analysis data, comparing ratings of current curriculum coverage with ratings of competency importance for each competency area.

Table 2: *Gap Analysis: Current Curriculum Coverage versus Importance Ratings*

Competency Area	Importance (I)	Current Provision (P)	Gap(I-P)	t-value	p-value	Effect Size (d)
Technical Knowledge	4.72	4.58	0.14	2.84	.005*	0.21
Problem Solving	4.83	4.39	0.44	9.32	<.001*	0.68
Communication	4.65	3.91	0.74	14.23	<.001*	1.04
Teamwork	4.59	3.84	0.75	13.56	<.001*	0.99
Digital Fluency	4.48	3.53	0.95	16.82	<.001*	1.23
Sustainability	4.27	3.46	0.81	12.64	<.001*	0.92
Interdisciplinary	4.39	3.27	1.12	18.47	<.001*	1.35
Ethical Reasoning	4.52	3.68	0.84	14.98	<.001*	1.10
Leadership	4.21	3.12	1.09	15.63	<.001*	1.14
Project Management	4.34	3.35	0.99	15.31	<.001*	1.18

*Note: Values are mean ratings on 1-5 scale. *$p < .05$ indicates significant difference between importance and provision.*

Table 2 reveals significant gaps between importance and current provision for all competency areas except technical knowledge, where the gap was small but statistically significant (t=2.84, p=.005, d=0.21). The largest gaps were observed for interdisciplinary collaboration (gap=1.12, d=1.35), leadership (gap=1.09, d=1.14), project management (gap=0.99, d=1.18), and digital fluency (gap=0.95, d=1.23). These findings indicate that while all competency areas are deemed important, current curricula are not adequately providing opportunities for development in key areas essential for future engineering practice.

The small gap for technical knowledge suggests that current curricula are relatively well aligned with technical knowledge requirements, consistent with historical emphasis on technical fundamentals in engineering education. However, the substantial gaps for professional skills and interdisciplinary competencies indicate that engineering education is not adequately preparing graduates for the multidimensional demands of contemporary engineering practice. These findings support the call for curriculum reform from the Engineers 2030 project and other initiatives.

The gap analysis reveals particular challenges in developing competencies that require authentic professional experiences and interdisciplinary engagement. Leadership, project management, and interdisciplinary collaboration are competencies that are difficult to develop through traditional lecture-based instruction, requiring experiential learning approaches and opportunities for practice in authentic contexts. The findings suggest that many institutions may be struggling to provide such opportunities, resulting in significant gaps between educational provision and professional requirements.

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H. Evaluation of Pedagogical Approaches

The study evaluated the effectiveness of different pedagogical approaches for developing engineering competencies. Table 3 presents ratings of pedagogical approach effectiveness for developing the competency areas identified as most important.

Table 3: *Perceived Effectiveness of Pedagogical Approaches for Competency Development*

Pedagogical Approach	Technical Knowledge	Problem Solving	Communication	Teamwork	Digital Fluency	Sustainability	Overall Effectiveness
Traditional Lectures	4.42 (0.68)	3.38 (0.92)	2.67 (1.04)	2.24 (0.98)	2.91 (1.02)	2.56 (1.08)	3.03
Problem-Based Learning	3.87 (0.81)	4.62 (0.57)	4.08 (0.79)	4.23 (0.75)	3.94 (0.85)	4.16 (0.82)	4.15
Project-Based Learning	4.12 (0.74)	4.55 (0.62)	4.24 (0.72)	4.38 (0.68)	4.02 (0.81)	4.32 (0.74)	4.27
Laboratory Work	4.35 (0.72)	4.18 (0.78)	3.12 (0.96)	3.68 (0.88)	3.52 (0.92)	3.26 (0.96)	3.69
Industry Placements	3.84 (0.89)	4.36 (0.74)	4.38 (0.72)	4.42 (0.69)	4.18 (0.78)	4.22 (0.76)	4.23
Team Projects	3.76 (0.86)	4.28 (0.76)	4.32 (0.71)	4.48 (0.64)	3.82 (0.87)	3.94 (0.84)	4.10
Simulation/Modelling	4.08 (0.78)	4.24 (0.76)	2.84 (1.02)	2.46 (1.06)	4.18 (0.76)	3.48 (0.92)	3.55
Online Learning	3.52 (0.92)	3.24 (0.96)	3.16 (0.98)	2.78 (1.04)	3.68 (0.92)	3.42 (0.96)	3.30

Note: Values are mean (standard deviation) on 1-5 scale where 1 = not effective, 5 = highly effective.

Table 3 reveals substantial variation in perceived effectiveness of different pedagogical approaches across competency domains. Traditional lectures were rated as effective for technical knowledge (4.42) but poorly suited for developing communication (2.67), teamwork (2.24), or sustainability competencies (2.56). This finding is consistent with critiques of lecture-based instruction for professional skills development, highlighting the need for diverse pedagogical approaches.

Project-based learning received the highest overall effectiveness rating (4.27) and was rated as highly effective across all competency domains, particularly for problem-solving (4.55), teamwork (4.38), sustainability (4.32), and communication (4.24). Industry placements were also highly rated overall (4.23) and were perceived as particularly effective for developing teamwork (4.42), communication (4.38), and sustainability (4.22). These findings support research indicating that experiential learning approaches and industry engagement are essential for developing the multidimensional competencies required for engineering practice.

Problem-based learning was rated as highly effective for problem-solving (4.62) and teamwork (4.23) but somewhat less effective for digital fluency (3.94) and sustainability (4.16). This pattern suggests that while PBL effectively develops problem-solving and collaborative skills, intentional integration of digital and sustainability content may be required to develop these competencies. The findings support the call for enhanced PBL frameworks incorporating Industry 4.0 technologies to develop digital competencies alongside professional skills (IEEE, 2025).

I. Analysis of the Digital Skills Gap

Given the significant gap identified for digital fluency, the study conducted detailed analysis of digital skills development across engineering disciplines. Table 4 presents ratings of specific digital competencies by perceived importance and current provision

Table 4: *Digital Competencies: Importance, Provision, and Gap Analysis*

Digital Competency	Importance (I)	Current Provision (P)	Gap (I-P)	t-value	p-value
Data Analysis	4.58 (0.61)	3.72 (0.92)	0.86	11.84	<.001*
Programming/Code	4.42 (0.74)	3.85 (0.96)	0.57	7.22	<.001*
AI/ML Applications	4.36 (0.78)	2.96 (1.08)	1.40	16.98	<.001*
Digital Design Tools	4.52 (0.66)	3.88 (0.92)	0.64	8.66	<.001*
Simulation/Modelling	4.48 (0.68)	4.06 (0.84)	0.42	6.12	<.001*
Data Visualisation	4.28 (0.76)	3.42 (0.98)	0.86	11.24	<.001*
Cybersecurity Awareness	4.02 (0.88)	2.84 (1.04)	1.18	13.92	<.001*
IoT/Connected Systems	4.14 (0.82)	2.92 (1.06)	1.22	14.56	<.001*
Digital Ethics	4.18 (0.80)	3.12 (1.02)	1.06	12.98	<.001*
Automation/Robotics	4.24 (0.78)	3.18 (1.04)	1.06	13.22	<.001*

*Note: Values are mean (standard deviation) on 1-5 scale. *$p < .05$ indicates significant difference between importance and provision.*

Table 4 reveals substantial gaps across all digital competency areas, with the largest gaps for AI and machine learning applications (gap=1.40), IoT and connected systems (gap=1.22), cyber security awareness (gap=1.18), and digital ethics (gap=1.06). These findings indicate that while digital competencies are recognized as critically important, current curricula are not adequately addressing these areas, particularly in emerging technology domains.

Simulation and modeling was the only digital competency where current provision approached importance ratings (gap=0.42), reflecting established integration of simulation tools in many engineering programs. However, the substantial gaps for AI, IoT, and cyber security indicate that engineering curricula have not kept pace with digital transformation, potentially leaving graduates unprepared for digitally-enabled engineering practice. This finding is particularly concerning given that 74 percent of engineering employers consider advanced digital skills critical for their workforce (Engineering Council, 2025).

The gap for digital ethics (1.06) is notable, as ethical reasoning more broadly also showed significant gaps. This suggests that current curricula may not be adequately preparing students to navigate the ethical implications of digital technologies, despite growing recognition of the importance of digital ethics in engineering practice. Integration of digital ethics throughout the curriculum, rather than as a standalone topic, may be necessary to develop this competency effectively.

J. Analysis of Sustainability Competency Development

Given the importance of sustainability for future engineering practice, the study examined approaches to developing sustainability competencies. Table 5 presents analysis of sustainability competency development across different pedagogical approaches.

Table5: *Sustainability Competency Development: Pedagogical Effectiveness and Integration*

Sustainability Dimension	Importance	Current Provision	Gap	Most Effective Approach	Least Effective Approach
Environmental Impact	4.38 (0.72)	3.62 (0.96)	0.76	PBL (4.34)	Lectures (2.68)
Sustainable Design	4.32 (0.76)	3.48 (0.98)	0.84	Project-Based (4.48)	Lectures (2.54)
Life Cycle Assessment	4.18 (0.82)	3.24 (1.02)	0.94	Industry Placements (4.26)	Online (3.12)
Circular Economy	4.12 (0.86)	2.98 (1.08)	1.14	Project-Based (4.32)	Lectures (2.38)

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Social Sustainability	4.08 (0.88)	2.86 (1.04)	1.22	Industry Placements (4.22)	Lectures (2.42)
Environmental Ethics	4.28 (0.78)	3.34 (1.02)	0.94	PBL (4.18)	Online (3.08)
Climate Adaptation	4.14 (0.84)	3.06 (1.06)	1.08	Industry Placements (4.34)	Lectures (2.44)
Policy/Regulatory	3.92 (0.92)	2.92 (1.08)	1.00	PBL (4.06)	Lectures (2.52)

Note: Values are mean (standard deviation) on 1-5 scale. Effectiveness ratings indicate mean effectiveness for that approach in developing the specific dimension.

Table 5 reveals substantial gaps between importance and current provision for all sustainability dimensions, with the largest gaps for social sustainability (gap=1.22), circular economy (gap=1.14), climate adaptation (gap=1.08), and policy and regulatory understanding (gap=1.00). These findings indicate that while sustainability is recognized as important, current curricula are not adequately addressing sustainability competencies, particularly in areas beyond environmental impact assessment.

Project-based learning and industry placements were identified as the most effective approaches for developing sustainability competencies. Project-based learning was particularly effective for sustainable design (4.48) and circular economy (4.32), while industry placements were most effective for climate adaptation (4.34), life cycle assessment (4.26), and social sustainability (4.22). These findings support research indicating that experiential learning approaches are essential for developing sustainability competencies, as they allow students to engage with authentic sustainability challenges and consider multiple stakeholder perspectives.

Traditional lectures were consistently rated as the least effective approach for developing sustainability competencies, with ratings ranging from 2.38 to 2.68 across dimensions. This finding suggests that while lectures may be useful for introducing sustainability concepts, they are insufficient for developing the applied competencies required for sustainable engineering practice. Integration of experiential learning approaches throughout the curriculum is essential for developing sustainability competencies effectively.

V. CONCLUSION

This study investigated engineering education, research, and skills development for future challenges, examining alignment between educational provision and industry requirements, and identifying effective strategies for developing competencies required for future engineering practice. The findings reveal significant gaps between current curriculum provision and competency requirements across multiple domains, particularly in digital fluency, sustainability competencies, interdisciplinary collaboration, and professional skills. These gaps are most pronounced in emerging technology areas and competencies requiring authentic professional experiences for effective development.

The study confirms that while technical fundamentals remain essential, contemporary engineering practice requires multidimensional competencies including systems thinking, ethical reasoning, adaptive expertise, and interdisciplinary collaboration. Experiential learning approaches, including project-based learning, problem-based learning, and industry placements, were identified as most effective for developing these competencies, while traditional lecture-based instruction was perceived as inadequate for professional skills development. The findings highlight the critical importance of industry-academia partnerships for curriculum development and skills provision, as well as the need for policy support for engineering education transformation.

VI. RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed for transforming engineering education to meet future challenges.

1. Curriculum Reform for Integrated Competency Development: Engineering curricula should be redesigned to integrate professional skills, digital fluency, and sustainability competencies throughout the curriculum, rather than treating these as separate or optional components. This requires mapping of competency development across the curriculum and intentional design of learning experiences that simultaneously develop technical and professional competencies. Integrated curriculum design should ensure that students have multiple opportunities to develop and practice competencies across their program of study.

2. Enhanced Experiential Learning and Industry Engagement: Institutions should expand experiential learning opportunities including project-based learning, work-integrated learning, and industry placements. These experiences should be structured to provide authentic professional challenges and opportunities for competency development across multiple domains. Industry partnerships should be strengthened to facilitate co-design of curricula, delivery of guest lectures and workshops, and provision of authentic project contexts.

3. Digital Transformation and Future-Ready Skills: Engineering curricula should be updated to incorporate emerging digital technologies including AI, IoT, data analytics, and digital design tools. Digital competencies should be developed across the curriculum, with emphasis on both technical digital skills and digital ethics. Institutions should invest in faculty development to ensure educators are prepared to integrate digital technologies effectively into their teaching.

4. Sustainability Integration Across the Curriculum: Sustainability should be integrated across the engineering curriculum, addressing environmental, social, and economic dimensions. Experiential learning approaches should be employed to develop applied sustainability competencies, with emphasis on sustainable design, life cycle assessment, and stakeholder engagement. Sustainability should be taught as an integral aspect of engineering practice rather than as an add-on topic.

5. Policy Support for Engineering Education Transformation: Governments and professional bodies should provide policy support for engineering education transformation, including funding for curriculum innovation, faculty development, and infrastructure. Accreditation standards should be updated to require demonstrated competency development across technical, professional, and sustainability domains. Incentives should be provided for industry-academia partnerships and work-integrated learning initiatives.

6. Enhanced Assessment of Competency Development: Institutions should develop robust assessment approaches for professional skills, digital fluency, and sustainability competencies. Assessment should include authentic tasks that require demonstration of integrated competency development, such as project portfolios, case analyses, and performance assessments. Assessment data should be used for continuous improvement of curricula and pedagogical approaches.

7. Lifelong Learning and Continuing Professional Development: Engineering education should prepare graduates for lifelong learning by developing self-directed learning skills and orientation to continuous professional development. Institutions and employers should collaborate to provide ongoing learning opportunities that enable engineers to maintain and develop competencies throughout their careers. Micro-credentials and flexible learning pathways should be developed to support lifelong learning in engineering.

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