Chapter 16
Navigating the Use of AI in Engineering Education Through a Systematic Review of Technology, Regulations, and Challenges

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ABSTRACT

The integration of artificial intelligence (AI) into engineering education has emerged as a transformative force, offering innovative tools to enhance teaching, learning, and administrative processes. This study presents a systematic review of the current landscape, focusing on the AI technologies application, the regulatory frameworks, and the challenges encountered in engineering education. The findings reveal how AI can improve student learning outcomes, personalize educational experiences, and automate complex

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processes. The review also addresses critical issues, such as ethical considerations and the imperative for regulatory compliance. Furthermore, it identifies key barriers to adoption, such as technological limitations and the preparedness of educators and students to embrace AI-powered solutions. This study provides a comprehensive understanding of the potential and limitations of AI in engineering education, offering actionable insights for educators, policymakers, and stakeholders aiming to foster effective and ethical AI integration in academic settings.

INTRODUCTION

Artificial intelligence (AI) has quickly become a transformative agent in education (Garcia, Arif, et al., 2024; Mangubat et al., 2025; Miller et al., 2025). In engineering education, educators can adopt advanced AI technologies to develop personalized, efficient, and engaging learning experiences (Gantalao et al., 2025; Ocak et al., 2023). For instance, generative AI (GenAI) systems (e.g., ChatGPT) offer personalized assistance that enables students to solve problems actively and foster a deeper understanding of engineering concepts (Qadir, 2023). The integration of AI with existing technologies, such as virtual reality (VR) and augmented reality (AR), allows learners to immerse themselves in simulated environments where they can engage with complex engineering topics more intuitively and experientially (Schleiss et al., 2022). The emergence of AI-driven tools—including machine learning (ML), natural language processing (NLP), and intelligent tutoring systems (ITS)—has opened new frontiers in engineering education. These tools, including AI-powered robots and tutors, enable learners to progress at their own pace and address areas of difficulty. Maximizing the usage of these pedagogical tools creates a more equitable and data-rich learning environment (Johri, 2020). Studies highlight the potential of these technologies to enhance student motivation and engagement by promoting interactive and accessible learning (Heck & Schouten, 2021). Collectively, these innovations help develop critical thinking skills and better prepare students for the complexities of the engineering profession.

However, with great power comes great responsibility—especially as we enter a realm where AI technologies require carefully crafted regulatory frameworks to ensure their ethical and responsible deployment. The thoughtful implementation of AI in education is critical, particularly given the sensitivity of student data and the potential for biases embedded in algorithms. Compliance with frameworks such as the General Data Protection Regulation (GDPR) is essential to safeguard student privacy and data security. Moreover, institutional policies must take a leading role in establishing transparency and accountability mechanisms that address algorithmic bias and promote the fair and equitable adoption of AI in educational contexts (Silva & Janes, 2023). Yet, translating these broad principles into practical guidelines remains a challenge as institutions struggle to balance innovation with regulatory compliance (Lu et al., 2022). In addition, the practical application of AI in engineering education is hindered by several barriers, including the high costs associated with acquiring and maintaining AI tools and a lack of technical expertise among educators. These efforts are further complicated by ethical concerns, particularly the persistence of biases within AI models (Heyn et al., 2021). The systemic nature of these challenges calls for a multifaceted approach—one that includes cost-effective solutions, professional development for educators, and strong institutional commitment.

MAIN FOCUS OF THE CHAPTER

This chapter explores the disruptive nature of AI in engineering education, including technological evolutions, regulatory considerations, and the challenges associated with implementing AI. Specifically, it focuses on how AI-based tools play a crucial role in enhancing learning outcomes, enabling seamless integration into engineering curricula, and addressing barriers to adoption. The chapter is guided by three overarching questions that contribute to a holistic understanding of how AI is becoming an integral part of engineering education:

1. **What AI technologies are currently used in engineering education?** This question examines the emerging tools and platforms being adopted, along with their usage levels and effectiveness in improving learning outcomes.
2. **What are the regulatory aspects to consider when applying AI in engineering education?** Analyzing regulatory frameworks offers insights into the mechanisms through which organizations can implement AI responsibly and ethically.
3. **What challenges are associated with implementing AI in engineering education?** Identifying tangible ethical and practical impediments enables the design of targeted solutions that support the smooth adoption of AI applications.

By addressing these questions, the study offers actionable insights for educators, policymakers, and technologists in harnessing the transformative potential of AI. Contributing to the literature on AI and education, this chapter underscores the importance of equipping future engineers with the skills necessary for a technology-driven era (Nti et al., 2021). Complementing the existing body of knowledge, this systematic study analyzes peer-reviewed literature, proceedings from major conferences, and up-to-date case studies to provide an in-depth overview of current AI practices in engineering education and the projected direction for future advancements. Adopting this lens allows readers to identify new trends, emerging technologies, and pragmatic approaches that can be leveraged to fulfill the promise of AI in education. The implications highlight the strategic significance of embracing AI to transform engineering education in ways that cultivate the competencies engineers need to succeed in increasingly complex, technology-driven environments. Moreover, the review identifies the synergistic relationship between AI technologies, ethical guidelines, and implementation strategies—essential frameworks for facilitating the ongoing discourse on the future of engineering education. This is a critical consideration in educational contexts, as it reinforces the need for a collective strategy toward AI integration that fosters innovation, equity, and ethical accountability.

BACKGROUND OF THE STUDY

AI in Education

More than 2,000 years ago, renowned ancient philosophers such as Socrates (469–399 BC), Plato (427–347 BC), and Aristotle (384–322 BC) explored theories concerning the emergence of new knowledge and its impact on human life—particularly on learning and teaching. The topics discussed by these philosophers remain relevant today, especially in relation to a transformative technology known as AI, which has introduced both benefits and challenges to the field of education (Ouyang & Jiao, 2021). AI refers to the capability of computer systems to perform tasks that typically require human intelligence. It has been developed to assist in various domains of life to enable individuals to complete tasks more efficiently, intelligently, and often in more engaging ways. This technology facilitates personalized learning and streamlines educational management, but it also raises important ethical and social concerns—particularly in terms of data privacy and the evolving relationship between humans and technology.

AI in education is instrumental in enhancing the learning process by making it more effective and efficient (Namatherdhala et al., 2022). It improves the educational experience through a range of innovations, such as automating time-consuming administrative tasks and developing modular prototypes for statistical reasoning, data visualization, and learning analytics (Alneyadi et al., 2023; Athilingam & He, 2024; Gupta et al., 2024; Lam et al., 2024; Shoaib et al., 2024). Leveraging data analysis, AI enables the creation of relevant and compelling learning experiences, supporting learners' development based on their individual capacities. Numerous studies have demonstrated the positive impact and significant benefits of AI in education. For instance, research has shown that AI is being successfully integrated into academic environments and student learning processes (Wang et al., 2023). Additionally, computer scientists have explored the theoretical and scientific foundations of AI in education and investigated the broader impact of AI technologies in educational contexts (Chen et al., 2020; Zawacki-Richter et al., 2019).

Engineering Education

AI is becoming an essential component of engineering education. It offers an engaging learning experience for students and enhances teaching effectiveness for educators. The integration of AI in engineering education opens up a wide range of applications, each offering its own benefits and challenges. For example, AI-powered chatbots provide more effective and practical learning experiences through personalized, interactive, and real-time support (Mthombeni et al., 2023). Additionally, combining project-based learning with Open Educational Resources (OERs) enables students to work on real-world problems, enhancing their intrinsic motivation and practical skills while shifting the lecturer's role toward that of a facilitator or guide (Schleiss et al., 2022). There is an urgent need to develop curricula that integrate AI with traditional engineering education. This integration is necessary to equip students with the skills to solve engineering problems using AI—such as in the development of self-driving vehicles, drone delivery systems, and the implementation of Artificial Narrow Intelligence (ANI) applications (Johri, 2020). It also enhances the learning experience in engineering design education by requiring continuous curriculum adaptation to new AI tools and ensuring that both teachers and students stay up to date with the latest AI applications and methodologies.

AI can also assist educators in efficiently performing routine tasks, such as assessments, thereby allowing them to focus on creating more interactive and personalized teaching strategies that improve the overall quality of education (Garcia et al., 2025; Johri, 2020). Furthermore, engineering programs have begun implementing web-based AI tools such as OpexAnalytics and CompareAssess, which are used to teach supply chain management and promote learning through evaluation. These tools have been shown to improve student perceptions and learning outcomes (Bosman et al., 2022). Moreover, Mthombeni et al. (2023) emphasized that AI chatbots enhance the learning experience in engineering design education by offering personalized, real-time support, reshaping both knowledge acquisition and skill development. Similarly, Xu and Ouyang (2022) highlighted the integration of robotics and AI in

STEM education, promoting hands-on learning while encouraging discussions about ethical considerations. These developments point to a future where AI not only augments engineering education but also redefines the roles of students and educators in shaping innovative, future-ready learning environments.

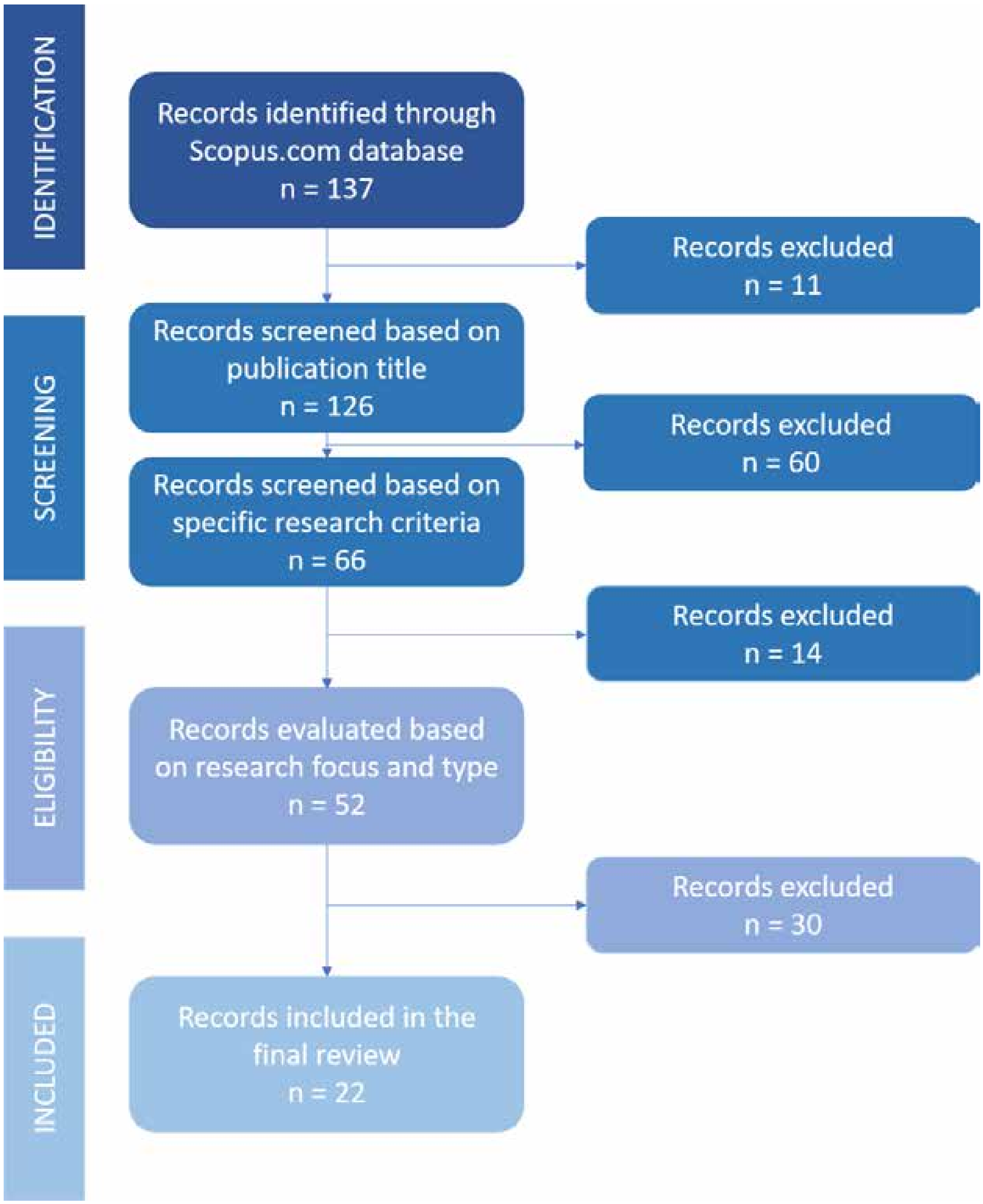
Gaps in Current Research on AI Integration in Engineering Education

Research on AI usability in engineering education has revealed several fascinating findings; however, there are still gaps that require further exploration. Santos et al. (2024) conducted a comprehensive literature review on the integration of Generative AI (GenAI) in teaching and learning processes. The study highlights the potential of GenAI technologies to enhance engineering educational practices. However, it focuses solely on information and communication technology (ICT) engineering education, leaving the broader applications of GenAI across other engineering disciplines unaddressed. Sah et al. (2024) also examined the integration of AI and large language models (LLMs) into software engineering education, offering a critical analysis of the literature, pedagogical frameworks, and persistent challenges. While the study emphasizes the ethical implications of using AI and LLMs, it does not propose comprehensive frameworks or educational strategies to integrate AI ethics deeply into the curriculum. Our research seeks to fill this gap by exploring AI ethics and the implementation of regulatory frameworks within engineering education. Al Husaeni et al. (2022) conducted a systematic review of the integration of chatbots as educational tools in science and engineering education. Although the research includes contributions from various countries, it does not examine how chatbots are utilized differently across educational contexts. There remains a need to investigate the effectiveness and challenges of AI technologies in diverse educational settings. Our research aims to bridge this gap by evaluating the use of AI across various engineering fields, as different disciplines may demand distinct pedagogical strategies or technologies.

METHODS

This study employed a systematic literature review (SLR) guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure a rigorous and transparent process in identifying, evaluating, and synthesizing relevant literature. The SLR approach was chosen for its suitability in exploring the integration of AI in engineering education, particularly in relation to technological applications, regulatory considerations, and implementation challenges (Arif et al., 2024; Arif et al., 2025; Lobo et al., 2025; Olugbade, 2025). Following the four principal phases of PRISMA—identification, screening, eligibility, and inclusion—the review process was conducted systematically to enhance the transparency, consistency, and accuracy of the findings. Relevant studies were retrieved from academic databases using predefined search terms, screened for relevance, assessed against inclusion and exclusion criteria, and included based on their alignment with the study's objectives.

Figure 1. Records selection process



Selection Process and Inclusion Criteria

During the literature search process, the author utilized the Scopus database with a focus on the integration of AI in engineering education. The search was limited to publications from 2019 to 2024 to ensure the study reflected current trends in AI applications within this field. The keywords (*AI* OR "*Artificial Intelligence*") AND *Engineering* AND (*Education* OR *Learning*) were used, yielding an initial result of 137 articles, reflecting the global scope of AI applications in engineering education. The selection process began with the identification phase, during which 137 records were retrieved from the Scopus database. In the first screening phase, these records were assessed based on their titles, leading to the exclusion of 11 records due to duplication and irrelevance. The second screening phase applied more specific criteria related to engineering education, resulting in the exclusion of 60 additional records, leaving 66 articles for further analysis. In the eligibility phase, the remaining 66 articles were critically evaluated based on their research focus and type. This assessment led to the exclusion of 44 articles that did not meet the study's inclusion criteria—such as lacking a clear focus on AI implementation in engineering education or failing to address associated challenges and regulatory aspects. Finally, 22 publications were selected for inclusion, as they met all criteria and provided critical insights into AI technology applications, regulatory considerations, and implementation challenges in engineering education. Figure 1 presents the PRISMA flow diagram, which visually outlines the study selection process across the four phases: identification, screening, eligibility, and inclusion.

Presented in Table 1 is the reference list along with the diverse research areas in engineering education. These studies covered a wide range of topics, such as the development of AI technologies, the creation of teaching materials, and the integration of AI into curricula. The reviewed studies employed various research methodologies, including descriptive approaches, research and development (R&D) models, pedagogical utility exploration, quantitative analysis, and qualitative analysis. These research studies also encompassed a broad spectrum of learner populations, ranging from high school students to those in higher engineering education. Moreover, they addressed multiple engineering disciplines, including geotechnical engineering, software engineering, systems engineering, civil engineering, electrical engineering, network engineering, control engineering, and materials science and engineering.

Table 1. List of studies employing AI in engineering education

No.	References	Implementation Field	Study Design/Method	Target Population
1	Nikolic et al. (2024)	Implementation of various AI technologies	Descriptive	Engineering Teachers & Students
2	Bordel and Alcarria (2024)	Implementation of AI technologies	Experimental	Network Engineering Students
3	Baltaci et al. (2024)	Integration of AI technologies	Qualitative Analysis	Electrical & Computer Engineering Students
4	Osunbunmi et al. (2024)	Teaching & Learning Process	Qualitative Analysis	Engineering Teachers & Students
5	Martel et al. (2024)	Teaching & Learning Process	Pedagogical Utility Exploration	Higher Engineering Education
6	Oliveira and Vrančić (2024)	Integration of AI technologies	Experimental	Control Engineering

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Table 1. Continued

No.	References	Implementation Field	Study Design/Method	Target Population
7	Modran et al. (2024)	Educational practices in engineering disciplines	Descriptive and Experimental	Higher Engineering Education
8	Rodríguez-Calderón and González-García (2024)	Educational technology in engineering education	Experimental and Descriptive analysis	Engineering Teachers & Students
9	Slomp et al. (2024)	Adaptive learning systems using AI technology	Qualitative analysis	Higher Engineering Education
10	Galos et al. (2024)	Integration of AI into curricula	Research and Development (R&D) Model	Materials Science and Engineering
11	Nikolic et al. (2023)	Engineering Education Assessment and Pedagogy	Descriptive	Higher Engineering Education
12	Asunda et al. (2023)	Integration of AI into K-12 education (STEM education)	Pedagogical Utility Exploration	High School Students
13	Ocak et al. (2023)	Integration of AI technologies	Descriptive	Civil Engineering
14	Johri (2020)	Integration of AI and ML in engineering education	Qualitative Analysis	Engineering Teachers & Students
15	Shvedchykova et al. (2023)	Development of new AI technologies	Research and Development (R&D) Model	Electrical Engineering Students
16	Yaghoubi et al. (2023)	Teaching & learning in engineering education	Experimental	Ph.D. and master's Program Teacher & Students
17	Memarian (2023)	The intersection of engineering education, cultural inclusivity, and AI-enhance pedagogy	Pedagogical Utility Exploration	Engineering Teachers
18	Moolman et al. (2023)	Virtual and remote learning environment	Research and Development (R&D) Model	Engineering Teachers
19	González et al. (2022)	AI Technology Development	Research and Development (R&D) Model	Software Engineering Students
20	Jaurez et al. (2022)	Integration of AI within the engineering lifecycle	Descriptive	Systems Engineering
21	Núñez and Lantada (2020)	Transformation of AI in engineering education	Descriptive	Engineering Teachers and Students
22	Lez'er et al. (2019)	Application of AI	Descriptive	Geotechnics and Engineering Students

The analysis of publication trends surrounding AI usability for engineering education is illustrated in Figure 2. The increasing number of research publications over the years indicates a growing research interest in this area. A notable peak in research activity was observed in 2024, with a maximum of 10 publications, followed by eight articles published in 2023. In both 2019 and 2020, there was a consistent output of one publication per year, whereas no publications were recorded in 2021. These findings suggest that AI usability in engineering education continues to be a significant focus within the academic community.

Figure 2. Number of annual publications

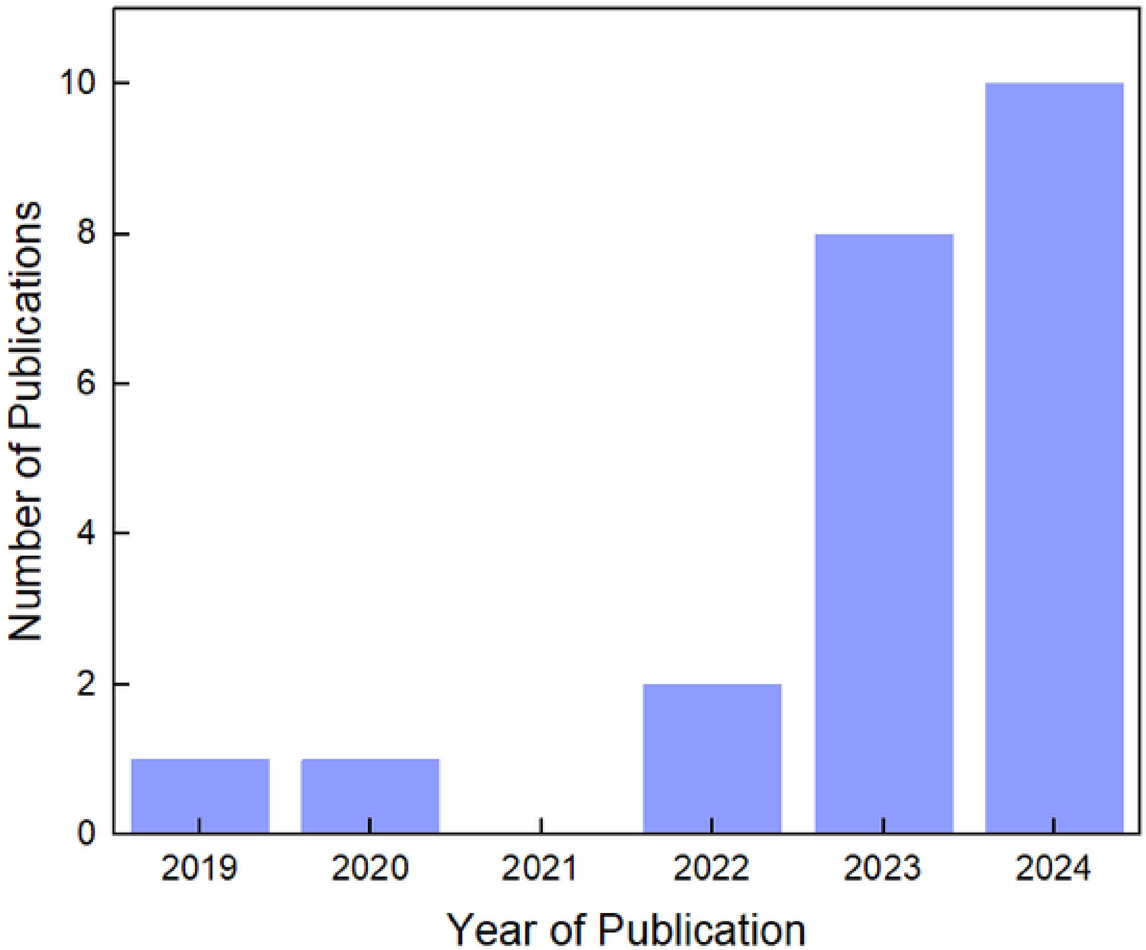
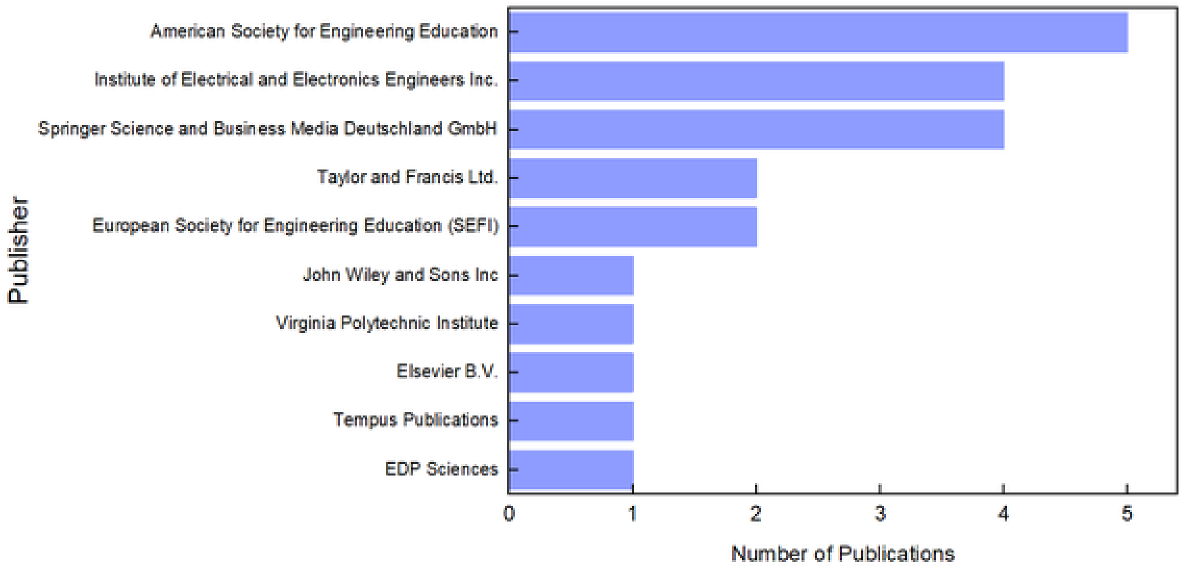


Figure 3 presents the distribution of publications across various publishers, highlighting the diverse contributions of different entities to the field. The American Society for Engineering Education (ASEE) leads with five publications, followed by the Institute of Electrical and Electronics Engineers Inc. (IEEE) and Springer, each contributing four publications. Taylor & Francis and the European Society of Engineering Education (ESEE) each published three papers, demonstrating their strong involvement in this research domain. Additionally, John Wiley and Sons Inc., Virginia Polytechnic Institute, Elsevier, Tempus Publications, and EDP Sciences each contributed one publication. This distribution reflects the broad engagement of publishers in advancing research on AI usability in engineering education.

Figure 3. Number of publications by publisher



An analysis of publication types reveals that conference proceedings are the predominant medium for disseminating research on AI usability in engineering education. Of the 22 studies analyzed, 15 were published as conference proceedings, five as journal articles, and the remaining two as book chapters. This distribution highlights the preference for conference proceedings as the primary platform for sharing preliminary results and facilitating academic discourse.

Data Collection and Analysis Process

To synthesize data from the selected studies, we applied a systematic approach that began with thematic analysis to identify key concepts and patterns in AI usability within engineering education. Each publication was carefully coded to highlight themes related to AI technologies, educational regulations, and implementation challenges in the context of engineering education. This qualitative thematic synthesis enabled the development of a comprehensive narrative that captured the diverse dimensions of AI integration in this field. The selected studies were coded according to predefined themes—such as AI technology, regulation, and challenges—with the aim of organizing and categorizing information based on relevant topics. Subsequently, these codes were analyzed to identify patterns and relationships among themes. Based on this analysis, a thematic narrative was developed to reflect the main findings from the reviewed literature.

In addition to thematic analysis, bibliometric analysis was conducted to visualize the relationships between key terms, offering a macro-level view of the field without relying on statistical methods. This approach allowed for the identification of prevailing trends and central topics related to AI in engineering education. Figure 4 illustrates the word cloud visualization, providing insights into the keywords most frequently appearing in the selected dataset. The top three keywords identified in the publications were *artificial intelligence, engineering education*, and *ChatGPT. Artificial intelligence* emerged as the most dominant term, underscoring its central role in this study. *Engineering education* was the second most frequent term, reflecting a strong emphasis on AI integration in this domain. Meanwhile, *ChatGPT* highlights a focus on specific AI tools and their practical use in educational settings. The prominence of ChatGPT indicates a growing interest in leveraging AI technologies to support teaching and learning in engineering education, which supports recent literature review in other disciplines (e.g., Garcia, 2025). Keywords related to ethics, academic integrity, and personalization point to broader challenges and considerations surrounding the application of AI in academia (Garcia, Garcia, et al., 2024).

Figure 4. Distribution of keywords

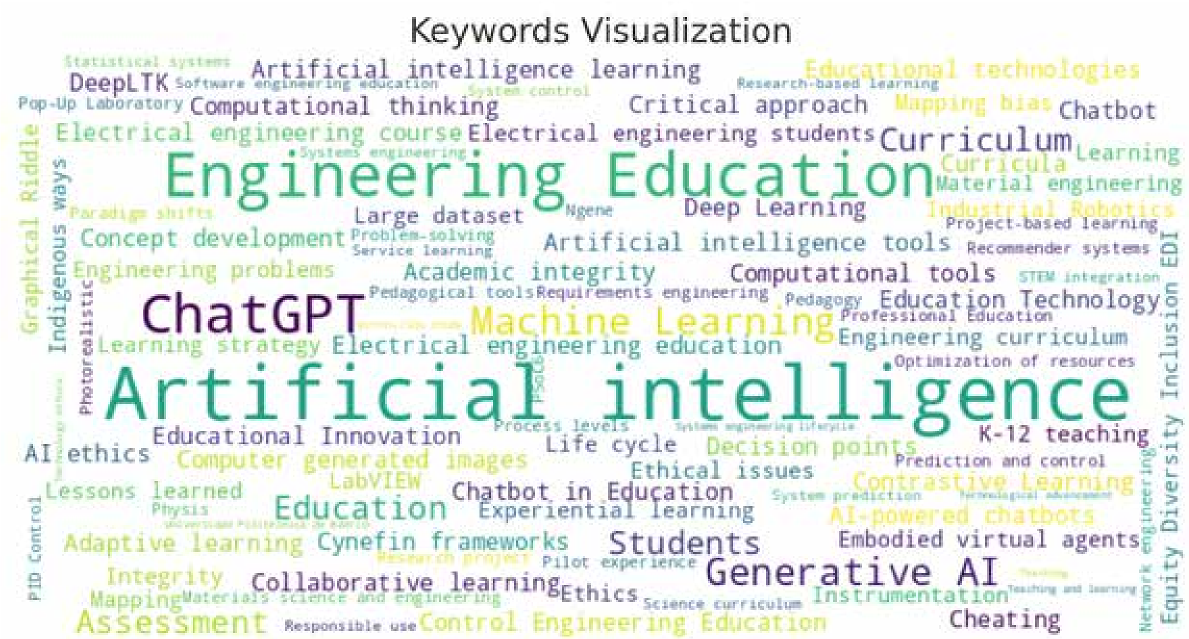
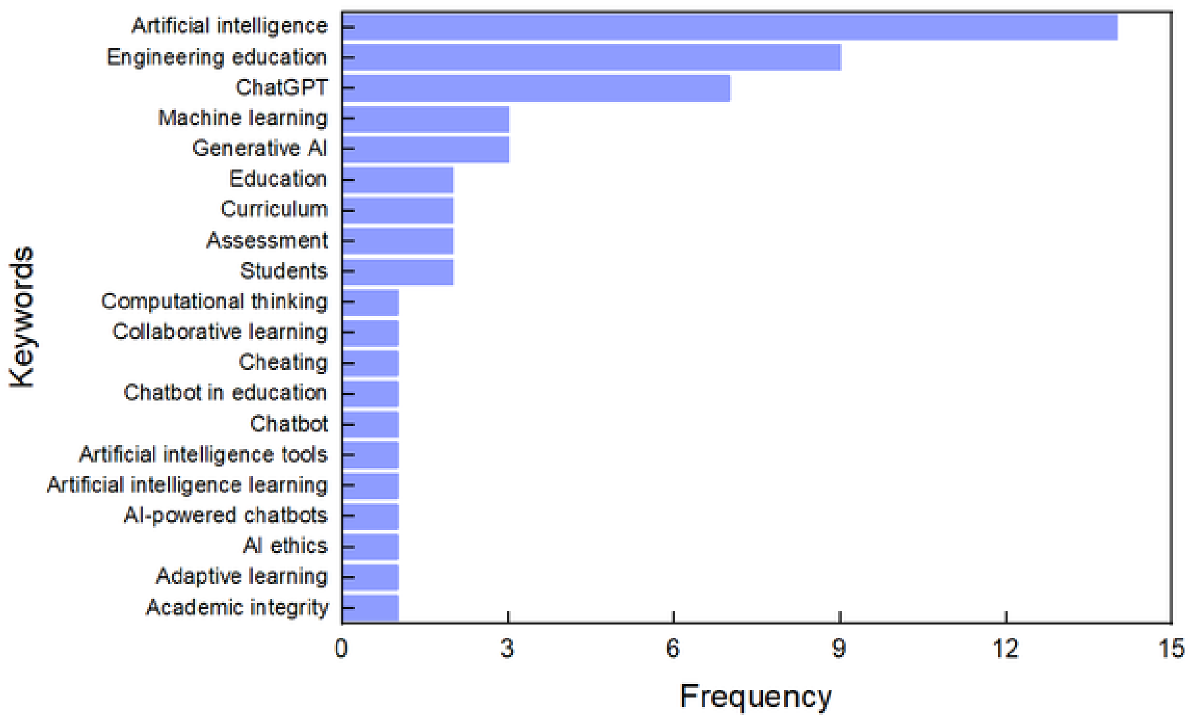


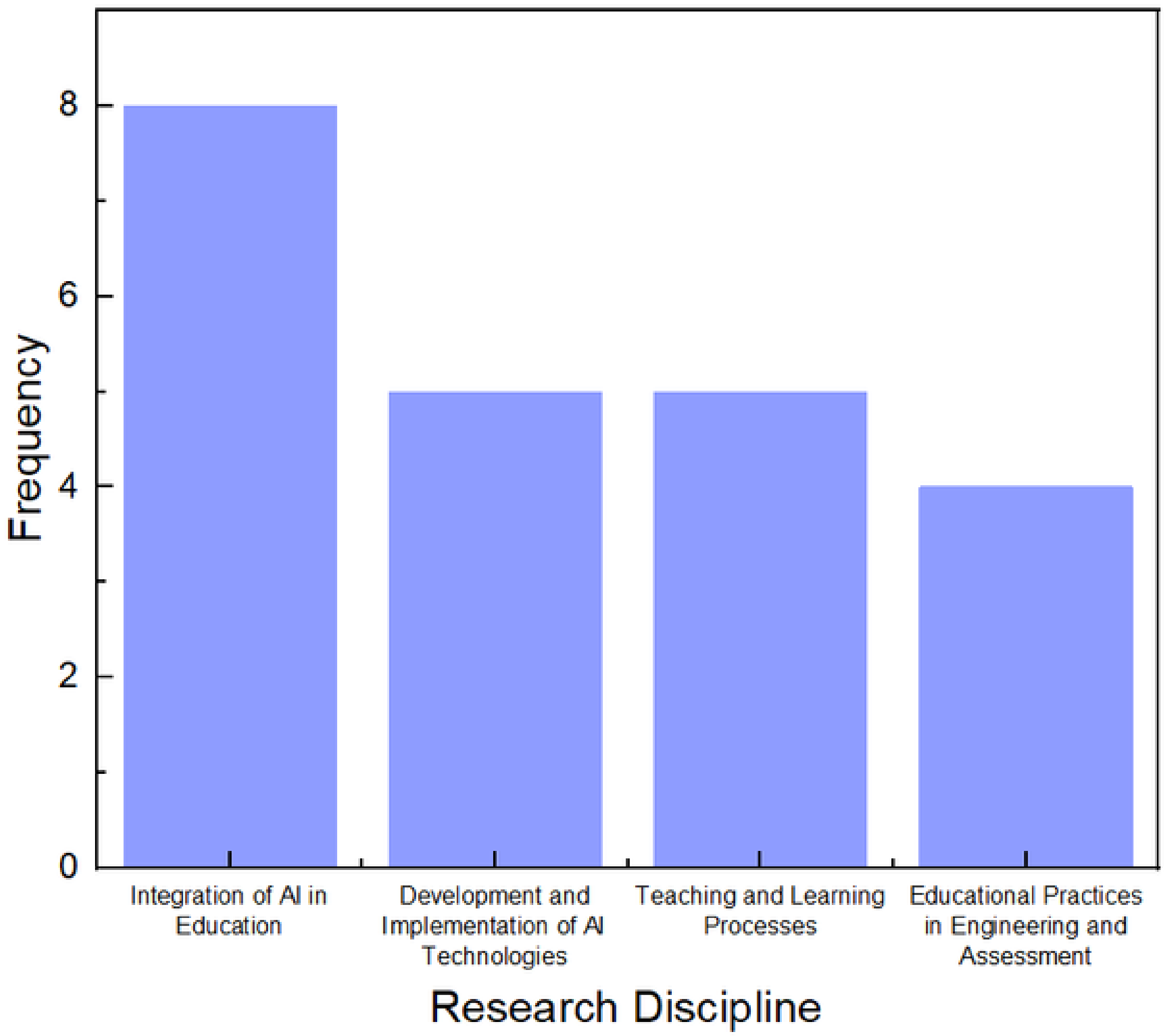
Figure 5 displays the frequency of the top 20 keywords found in the 22 selected papers. This visualization clearly highlights the prevalence and relationships among key terms such as *artificial intelligence, engineering education, ChatGPT, machine learning*, and others. These terms underscore their central role in shaping the current research landscape. Furthermore, the presence of terms like *generative AI*, *education*, *curriculum*, and *assessment* demonstrates a strong connection to engineering education and teaching methodologies. The inclusion of phrases such as *ChatGPT, chatbots in education*, and *AI-powered chatbots* also reflects a growing interest in the application of AI tools to enhance educational processes. This emphasizes researchers' focus on using these tools to improve the learning experience and outcomes for students. Notably, ethical considerations are also evident, as seen in the presence of terms like *AI ethics* and *academic integrity*, indicating attention to the ethical challenges associated with the use of AI in education.

Figure 5. Top 20 keywords in engineering education



The distribution of research disciplines is illustrated in Figure 6. The selected studies were categorized into four areas according to the implementations listed in Table 1. The most common discipline in education is AI integration, which includes eight implementation fields. This category encompasses a wide range of AI applications and integration strategies in areas such as engineering education, K-12 STEM education, curriculum design, and the engineering systems lifecycle. Next, five implementation fields were classified under the development and implementation of AI technologies, focusing on the technical and practical aspects of AI, including the creation, deployment, and refinement of these tools. The teaching and learning processes discipline also includes five implementation fields, examining how AI can enhance pedagogical approaches and learning environments, such as through adaptive learning systems, innovative teaching methods, and virtual or remote learning platforms. Finally, four implementation fields were grouped under educational practices in engineering and assessment. This discipline focuses on improving educational quality and inclusivity within engineering, covering areas such as technology adoption, assessment methods, and culturally responsive practices.

Figure 6. Distribution of research disciplines



Following the selection of publications, each article was critically analyzed. This analysis involved examining the technologies used, the regulatory frameworks applied, and the challenges encountered in implementation. The objective was to gain a comprehensive understanding of the context, methodologies, findings, and overall contributions of each study.

RESULTS AND DISCUSSION

The Integration of AI Technology in Engineering Education

Previous studies have shown that supporting technologies are being applied to optimize the role of AI in different domains, particularly in engineering education. AI plays a vital role in helping humans complete a wide range of tasks more efficiently and engagingly. These supporting technologies are designed to enhance performance in assessment processes, enrich teaching methods, and support engineering-based learning environments (Nikolic et al., 2024).

The AI development roadmap for the period 2020–2030 is presented in Figure 8. This roadmap outlines scientific, technological, and educational goals aligned with the United Nations 2030 Agenda. It begins with an analysis of AI's emergence as a supportive tool in educational practices, particularly in teaching. The study ultimately proposes the concept of a “smart university,” which leverages AI technologies to improve academic processes while also identifying key challenges in ensuring the sustainable use of AI in engineering education. One critical factor in the successful implementation of AI is the development of adequate capacity-building programs and training for educators, enabling them to effectively use AI to support teaching and prepare students for the future (Bozkurt et al., 2024; Núñez & Lantada, 2020).

Figure 8. AI in engineering education: Current situation and roadmap

Traditional face-to-face and laboratory assessments remain effective methods for maintaining academic integrity. These approaches can be complemented by technologies such as ChatGPT to support student learning. For example, ChatGPT can provide high-quality annotations, allowing students to compare their solutions with AI-generated outputs and use these comparisons to deepen their understanding (Nikolic et al., 2023). However, as AI libraries rapidly evolve, the academic community must continually adapt assessment approaches to ensure both relevance and integrity. One promising strategy is the reverse assessment approach, where students are engaged in critical thinking tasks that require them to analyze and evaluate the output of technologies like ChatGPT. Research indicates that while AI technology offers numerous benefits, it must be implemented thoughtfully to mitigate potential negative impacts (Nikolic et al., 2024). Educators are significantly affected by the integration of AI in engineering education. AI simplifies the process of delivering instructional content by enabling real-time adaptation of materials based on student feedback and performance metrics. It also aids in laboratory preparation by predicting equipment needs, optimizing settings, and simulating potential outcomes—thereby enhancing hands-on lab experiences. Additionally, AI supports student learning by providing accessible explanations, visualizations, and simulations that help students grasp complex concepts quickly and effectively (Baltaci et al., 2024).

Despite its advantages, AI development in education—particularly in engineering—also presents challenges. Concerns related to ethics, data security, and overreliance on technology need to be addressed. Excessive dependence on AI can potentially diminish students' creativity (Garcia, 2024). To harness the full potential of AI, educators require adequate training on how to integrate these technologies effectively into the learning process. Therefore, further research is essential to develop strategies that address these challenges and ensure AI is used responsibly and productively. Looking ahead, AI is expected to become more integrated, intelligent, and accessible—supporting advancements across multiple disciplines, including engineering education. With its capacity to enhance accessibility, efficiency, and engagement, AI has the potential to revolutionize engineering education, making it more inclusive and responsive to diverse learner needs. Ultimately, AI can usher in a new era of engineering education that is more effective, affordable, and globally accessible (Núñez & Lantada, 2020). Analysis of AI integration in engineering education shows benefits such as customization of teaching and early detection of difficulties students face during teaching and learning activities (Slomp et al., 2024).

The Regulations for AI Utilization in Engineering Education

The role of AI technology in engineering education offers immense opportunities to revolutionize teaching and learning. However, alongside these benefits come challenges that necessitate well-defined regulations to ensure the ethical, safe, and effective use of AI. A key challenge, as identified in the study *Artificial Intelligence in Education: Challenges and Opportunities for Sustainable Development*, is the need for policy frameworks to guide the responsible use of AI in alignment with global goals, including the UN's 2030 Agenda for Sustainable Development. Similarly, *The Impact of Artificial Intelligence on Learning, Teaching and Education*, a report by the EU Commission, underscores the importance of regulating AI to harness its transformative potential while mitigating associated risks (Núñez & Lantada, 2020).

To leverage the capabilities of AI technologies and ensure a positive influence on teaching and learning, policymakers must design and implement regulations that benefit all stakeholders—educators, institutions, and especially engineering students. While engineering students must be adept in using advanced technologies, they also need strong critical thinking skills to verify and contextualize information. Overreliance on AI could hinder the development of foundational competencies such as problem-solving, analytical reasoning, and collaboration. Therefore, students should be encouraged to cross-reference AI-generated outputs with trusted academic sources, including textbooks, scholarly articles, and faculty guidance (Nikolic et al., 2024; Xiao et al., 2025). Policies must aim to strike a balance between technological application and the cultivation of human cognitive and creative skills—such as limiting AI use in certain hands-on or conceptual learning tasks. Importantly, AI should be viewed as a supplementary tool rather than a replacement for physical courses or laboratory experiences. Practical, hands-on learning remains a core component of engineering education, and designing real-world experiments in engineering disciplines can be challenging yet essential (Bordel & Alcarria, 2024; Modran et al., 2024).

Furthermore, regulations should require institutions to provide structured training programs for educators. These programs should cover the technical, pedagogical, and ethical dimensions of AI integration. Educators must be equipped not only to use AI tools but also to guide students in their ethical and effective application. Regulatory models like the *Academic Integrity Enforcement Pyramid* emphasize the importance of institutional commitment to responsible AI use (Nikolic et al., 2024). Governments and institutions should also fund and support research initiatives aimed at developing sustainable, AI-integrated educational models aligned with national education goals. Regular audits and internal reviews must also be mandated to ensure that AI is being used safely, ethically, and effectively in educational settings. A crucial component of AI regulation in engineering education is data protection and privacy. Since AI systems often rely on big data—including students' learning outcomes, preferences, and interactions—regulations must ensure that this data is processed securely. This includes enforcing encryption, access controls, and transparency regarding how student data is collected and used. Regulations must also align with local and international standards, such as GDPR, to ensure robust protection of learner data (Johri, 2020; Slomp et al., 2024). In addition, ethical regulation is essential to prevent algorithmic bias that could unfairly impact academic assessments or reinforce inequalities. Automated evaluation tools, for example, may inadvertently disadvantage certain groups. Broader ethical concerns include fairness, transparency, potential misuse, and the fear of AI displacing human educators. Regulations should require that AI systems be fair, inclusive, and transparent. Interdisciplinary expert panels can be instrumental in auditing algorithms and minimizing biases. With the rapid rise of generative AI, it is imperative to consider both its short-term implications and long-term effects on education (Acut et al., 2024).

When well-designed and properly enforced, AI regulations can minimize the risks of misuse, promote educational equity, and ensure that AI supports—not disrupts—core educational values. Such regulations will help educators deliver material in real time and assist students in understanding concepts more efficiently and deeply. Appropriate policy frameworks will not only support ethical AI integration but also enhance the inclusivity, personalization, and overall quality of engineering education. Looking ahead, further studies are needed to assess AI's strengths, limitations, and emerging opportunities in both engineering and pedagogical contexts (Osunbunmi et al., 2024). Ultimately, while AI has tremendous potential to advance engineering education, this potential can only be fully realized through thoughtful regulation, mature ethical considerations, and comprehensive training for educators (Slomp et al., 2024).

Recommendations for Addressing AI Challenges in Engineering Education

Among the 22 selected papers and the top 20 identified keywords, a clear emphasis is placed on the use of AI, particularly in the context of learning development. AI has a significant impact on engineering education, influencing teaching, learning, and assessment processes. For example, the integration of computational thinking (CT) into STEM education has been shown to develop critical and analytical thinking skills, including problem-solving capabilities. STEM learning environments help students acquire essential AI and ML competencies (Asunda et al., 2023). Additionally, AI-powered virtual assistants can support students in identifying similar problems related to their academic projects. Personalized AI assistants help reduce the time needed to solve complex challenges by offering relevant and timely solutions (González et al., 2022). Despite these benefits, AI also presents several challenges. One such challenge is academic integrity, particularly in relation to detecting plagiarism and misconduct during assessments. For instance, Nikolic et al. (2023) explored how ChatGPT performed across assessment prompts from ten subjects at seven Australian universities. The findings revealed that ChatGPT passed several assessments and excelled in some types, raising questions about the validity of traditional assessment formats in the presence of generative AI. Apart from that one example, integrating AI and engineering education has several challenges. The 22 selected papers address the following challenges in engineering education: academic integrity, pedagogical adaptation, discipline-specific implementation, curriculum integration and institutional, computational thinking, and interdisciplinary and ethical concerns. The following describes recommendations for the challenges that must be faced.

Ensuring Academic Integrity

Challenge: The emergence of generative AI tools like ChatGPT, GitHub Copilot, and Google Gemini has transformed how students approach assignments and assessments, posing risks to academic integrity. Nikolic et al. (2024) benchmarked ChatGPT's capabilities across institutions and found that its performance in academic settings complicates efforts to ensure fair evaluation. A key challenge lies in redesigning assessments that limit overreliance on AI tools while maintaining academic rigor. Educators must also teach students to use AI responsibly, leveraging its benefits without encouraging dishonesty. Further issues include AI-generated bias, inaccuracies, and over-dependence. Policies must clarify that ChatGPT and similar tools are intended as supplementary aids—not replacements for physical classes or laboratory experiences (Modran et al., 2024). Nikolic et al. (2024) recommend shifting towards open-book formats, oral examinations, and project-based assessments to counter AI misuse.

Recommendation: To safeguard academic integrity, institutions should implement comprehensive policies that combine open-book exams, oral assessments, and project-based evaluations. These formats can help reduce dependence on generative AI by assessing students' understanding through application and articulation. Additionally, the use of AI-detection tools should be mandated to identify possible misuse and ensure consistent enforcement. These strategies must be widely communicated across institutional levels and incorporated into standard academic policies to serve as benchmarks for responsible AI integration.

Reinforcing Pedagogical Practices

Challenge: AI introduces novel opportunities for teaching and learning, but its successful implementation requires a shift in pedagogical approaches—something many educators are not yet fully equipped to undertake (Acut et al., 2025). Núñez and Lantada (2020) identified a key challenge: striking a balance between harnessing AI's potential and preserving traditional engineering education's emphasis on critical thinking and problem-solving. Baltaci et al. (2024) found that integrating AI into electrical engineering requires educators to transition from instructor-centered models to more collaborative, AI-enhanced approaches. However, a significant barrier remains the lack of comprehensive faculty training programs. Rodríguez-Calderón and González-García (2024) also emphasized that current AI-enhanced models often fail to consider discipline-specific requirements and diverse learning styles. Bordel and Alcarria (2024) noted that while AI tools can boost engagement, they may not align well with all students' technological competencies. González et al. (2022) pointed out that virtual AI assistants can personalize learning, yet challenges persist in ensuring compatibility with existing pedagogical frameworks and promoting active student participation.

Recommendation: Faculty training programs should prioritize AI-enhanced pedagogical methods, focusing on active learning strategies, collaborative projects, and hybrid models that combine traditional and AI-driven instructional approaches. These programs must also address digital literacy and instructional design to ensure accessibility for both educators and students.

Overcoming Discipline-Specific Barriers

Challenge: Integrating AI into specialized engineering disciplines—such as civil, materials, or geotechnical engineering—requires domain-specific adaptations that are often resource-intensive and technologically complex. Ocak et al. (2023) emphasized the need for tailored AI training datasets and computational resources to enable meaningful integration in civil engineering. Galos et al. (2024) highlighted the difficulty of introducing AI to disciplines without a strong tradition in CT or computer programming. Lez'er et al. (2019) pointed out the steep learning curve and lack of tools tailored to geotechnics. Oliveira and Vrančić (2024) analyzed the use of Generative Pre-trained Transformers (GPTs) in control engineering and stressed the need for AI tools to provide technically accurate, context-specific outputs without oversimplifying complex concepts. Similarly, Yaghoubi et al. (2023) showcased innovative uses of AI in instrumentation engineering but also revealed challenges in applying AI creatively within technically demanding contexts. These studies collectively underscore the importance of discipline-specific AI solutions and cross-disciplinary collaboration.

Recommendation: Institutions should foster collaboration between AI specialists and engineering faculty to develop tailored AI applications for specific disciplines (Acut et al., 2025). Investments should be made in research, computing infrastructure, and simulation tools that allow students to apply AI to real-world engineering scenarios. Pilot programs, project-based learning, and case-based learning models can further facilitate this transition.

Redesigning Curricula for AI Integration

Challenge: Integrating AI into engineering curricula involves overcoming challenges related to resource constraints, faculty preparedness, and maintaining a balance between traditional engineering content and AI education. Shvedchykova et al. (2023) emphasized the paradigm shift needed to shift from theory-based curricula to practical, AI-driven learning. Memarian (2023) discussed the need to localize AI curricula to reflect cultural diversity and contextual relevance—an issue compounded by limited resources and expertise in many regions. Slomp et al. (2024) noted the difficulties of scaling AI-enhanced learning systems across institutions with varying levels of technological infrastructure. Jaurez et al. (2022), through the application of the Cynefin framework, highlighted the complexity of predicting and managing learning processes in AI-based systems, underscoring the need for innovative methodologies.

Recommendation: Universities should adopt a phased approach to curriculum redesign, beginning with AI-focused elective courses and interdisciplinary collaborations. AI should be embedded within traditional engineering problems to ensure relevance and contextual learning. Faculty development programs and institutional policies should support gradual integration, ensuring that all stakeholders are equipped to manage the evolving educational landscape.

Building Computational Literacy

Challenge: The integration of AI technologies often requires a foundational understanding of CT across disciplines, which presents an additional barrier in engineering education. Asunda et al. (2023) highlighted the difficulty of embedding CT into engineering curricula as a prerequisite for meaningful AI adoption. Many students and even educators lack the computational literacy necessary to fully leverage AI tools and techniques.

Recommendation: Engineering programs should introduce CT early in the curriculum by embedding AI literacy modules into foundational engineering courses. Moreover, interdisciplinary collaboration with computer science and data science departments should be encouraged to help students and faculty build essential computational skills and foster AI readiness.

Addressing Ethical Concerns and Accessibility

Challenge: The use of AI in education raises critical ethical concerns, especially related to fairness, transparency, accessibility, and the potential erosion of traditional educational models. Moolman et al. (2023) discussed the development of photorealistic AI-based virtual lecturers, revealing how such technologies challenge established norms of teacher authenticity and human interaction in the classroom. Similarly, Martel et al. (2024) explored the risks of bias embedded in AI algorithms and the diminishing human-centric nature of education. Osunbunmi et al. (2024), pointed out that generative AI tools may exacerbate inequalities, as underprivileged students often lack the resources to effectively access and utilize these technologies. These ethical and accessibility concerns require continuous attention and inclusive policy development.

Recommendation: Educational institutions should establish and enforce ethical guidelines for AI use in teaching and learning environments. These guidelines must ensure transparency, fairness, and accountability—particularly in AI-driven assessment systems (Garcia et al., 2025). Investments should be made in the development of accessible AI tools to ensure equitable learning opportunities for students across diverse socio-economic backgrounds.

CONCLUSION

AI is not only a new tool in learning but also part of a broader philosophical shift in how we understand teaching, learning, and knowledge creation. In the context of engineering education, AI offers transformative opportunities to enhance teaching practices, personalize learning, and modernize assessment methods. However, its integration also presents a range of challenges, including concerns about academic integrity, pedagogical adaptation, discipline-specific constraints, curriculum redesign, computational literacy, and ethical use. Addressing these challenges requires a strategic, multifaceted approach. Institutions must safeguard academic integrity through innovative assessment methods, train faculty in AI-supported pedagogies, invest in infrastructure for discipline-specific AI applications, and gradually integrate AI into existing curricula. Strengthening computational literacy by embedding foundational AI and data science concepts early in the program is equally crucial. Furthermore, ethical considerations must be central to policy development to ensure fair, transparent, and inclusive use of AI technologies. As AI becomes increasingly embedded in educational systems, future research should focus on scalable and equitable solutions tailored to the diverse needs of engineering education. With sustained investment in infrastructure, training, and ethical governance, AI has the potential to make engineering education more effective, engaging, and accessible—empowering future engineers to thrive in a rapidly evolving technological landscape.

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KEY TERMS AND DEFINITIONS

Artificial Intelligence (AI): A field of computer science focused on creating systems capable of performing tasks that typically require human intelligence, such as learning, reasoning, problem-solving, and language processing.

ChatGPT: An advanced language model developed by OpenAI that generates human-like responses in natural language, often used in educational settings for tutoring, answering questions, and interactive learning support.

Engineering Education: An academic discipline that prepares students for careers in engineering through a combination of theoretical instruction, applied learning, laboratory work, and project-based experiences.

Generative AI: A type of machine learning technology that produces new content—such as text, images, or audio—based on patterns in training data, often used to enhance creativity, automate writing tasks, or personalize educational content.

Open Educational Resources (OER): Freely available and openly licensed instructional materials that can be used, adapted, and shared to support learning, including textbooks, videos, assignments, and other teaching tools.

Systematic Literature Review: A structured research method used to collect, evaluate, and synthesize existing studies on a specific topic using predefined criteria and procedures. It aims to provide a comprehensive and unbiased summary of current knowledge, often following frameworks like PRISMA to ensure transparency and replicability.