

INTEGRATION OF ARTIFICIAL INTELLIGENCE INTO ENGINEERING EDUCATION: ANALYSIS AND PROSPECTS

This article presents a review of recent scientific publications devoted to a comprehensive study of the integration of artificial intelligence (AI) into engineering education. Innovative teaching and learning methods that actively use the potential of AI are considered in detail, such as the creation of personalized learning trajectories, the use of intelligent tutoring systems for adaptive interaction, the use of simulations and virtual environments for practical experience, the implementation of gamification to increase engagement, and automated assessment for effective feedback. Innovative teaching methods that have been significantly improved by the integration of AI are thoroughly analyzed, including the development of self-directed and autonomous learning, the expansion of collaborative learning opportunities, the use of interactive simulations and virtual reality for deep immersion, the provision of personalized feedback and guidance, as well as integration into the learning process to develop key 21st century skills. This paper provides an in-depth analysis of the current state of AI integration in engineering education, covering the levels of actual implementation of various AI tools, the main focus on specific cutting-edge technologies, the diverse applications of AI in the educational process, and the perceptions of both teachers and students regarding the benefits and potential challenges. The prospects and forecasts for the future development of AI in engineering education are covered in detail, including the expected spread of hybrid learning models, further personalization of educational programs, growing attention to the ethical aspects and responsible use of AI, and the need to develop new competencies in teachers and students. Key trends and promising directions for further research in this area are identified, and the main challenges and potential barriers that may arise on the path to successful integration of AI in engineering education are discussed in detail.

Key words: artificial intelligence, engineering education, innovative teaching methods, innovative learning methods, personalized learning, adaptive systems, intelligent tutoring systems, generative AI, analysis, prospects.

Artificial intelligence (AI) is showing significant transformative potential in various sectors, and the education sector is no exception. In higher education, especially in engineering disciplines, there is a growing recognition of the relevance and potential impact of AI in revolutionizing teaching and learning methodologies. The growing focus on AI's capabilities is driven by its ability to offer adaptive, personalized, and immersive educational experiences, overcoming the limitations of traditional teaching methods. Due to the rapid development of AI, in particular generative AI, there is a significant need to understand its role in education [1, 2]. This urgency is reflected in the increasing number of publications exploring this intersection. The mention of ChatGPT's release and the skyrocketing growth of the AI market in education – projected to grow to \$6 billion by 2025 with a CAGR of 47 % between 2020 and 2025 – point to a recent surge in interest and research. This is indicative of a dynamic and rapidly evolving field where understanding the latest trends is critical for educators and institutions to remain competitive and effective.

The issues of transformation of engineering education based on the use of artificial intelligence are widely discussed by the world scientific community, which can be seen from publications in journals on engineering education [3-8, etc.] and on artificial intelligence [9-13, etc.].

Understanding the latest trends in the integration of AI into engineering education is critical for educators and educational institutions to remain competitive and effective in a rapidly evolving educational environment and is timely and critical to understanding and harnessing the potential of AI in the field.

The purpose of the work is to analyze the process of integrating artificial intelligence technologies into the system of engineering education, to study innovative methods of teaching and learning, as well as to assess their impact on the educational process, to consider current achievements in this area, to identify the main challenges and problems, to propose promising approaches to the introduction of AI in educational programs and to assess possible areas for further development.

The history of the use of artificial intelligence in engineering education dates back to the 1960s, when the first attempts to use computers for learning appeared. During this period, computer-assisted instruction (CAI) systems were developed, and the focus was on programmed learning and automated testing.

In the 1970s and 1980s, Intelligent Tutoring Systems (ITS) appeared, which used artificial intelligence to adapt the educational process to the individual needs of students. Expert systems have also been developed for diagnosing students' mistakes.

The 1990s saw the rise of web technology and online learning. Artificial intelligence began to be used to create adaptive web courses, and Learning Management Systems (LMS) with elements of artificial intelligence also appeared.

The 2000s saw an increase in data volumes and the development of machine learning methods. Artificial intelligence has been used to analyze data on student success and predict their outcomes, and adaptive learning platforms have emerged.

The 2010s are still characterized by the rapid development of deep learning technologies and large language models. Artificial intelligence is used to create chatbots, virtual assistants, and intelligent learning materials, and is also being actively implemented in higher engineering education.

Innovative teaching methods based on AI

➤ *Personalized learning and adaptive systems:* AI algorithms analyze academic performance, learning styles (e.g., the Felder-Silverman model), and student needs to adapt content, pacing, and feedback. For example, AI can predict changes in learning styles [14]. Adaptive learning platforms adjust difficulty and content in real-time based on student progress. where AI acts as a key enabler for creating truly individualized educational experiences. This allows students to meet a variety of learning needs, which is a limitation of traditional one-size-fits-all approaches. The use of models such as the Felder-Silverman model demonstrates a structured approach to understanding and meeting these diverse needs. Several passages explicitly mention consideration of individual learning styles and paces. AI's ability to continuously assess and adapt based on large amounts of student performance data provides a level of personalization that was previously impractical, potentially improving self-efficacy and attitudes toward education.

➤ *AI-based intelligent tutoring systems (ITS):* ITS provide personalized guidance, feedback, and support by mimicking personalized learning [15]. An example is Carnegie Learning's MATHia system. Examples include systems that adapt to learners' needs, identify knowledge gaps, and offer targeted support. ITS offer scalable and consistent personalized support, potentially bridging the gap between needs students and the available time of teachers. They can provide immediate feedback, which is crucial for effective learning and building student confidence. Fragments B3 and S62 emphasize the adaptive nature of IES, which adapt guidance based on individual student needs and mimic individualized learning. This personalized feedback and support can help with specific learning moments and boost students' confidence.

➤ *AI-supported simulations and virtual labs:* AI creates interactive simulations and virtual environments for hands-on learning and experimentation in a safe environment. Students can visualize complex engineering concepts (e.g., electromagnetic theory, control systems) and apply principles in realistic scenarios. more affordable and cost-effective. AI can even analyze the performance of systems under different conditions. Fragments B1 and S60 specifically mention virtual laboratories for electrical engineering, allowing experimentation with complex systems such as power grids. This solves the problem of providing hands-on experience to all students, especially in resource-constrained settings, and promotes a deeper understanding of project design and equipment use [16].

➤ *AI-based gamification:* Incorporating game elements to increase student engagement and motivation. Interactive challenges and rewards can foster deeper learning of concepts. AI can be used to create engaging and enjoyable learning experiences [17]. Gamification can make learning more enjoyable and increase student motivation, leading to better retention and understanding of engineering principles. AI can personalize these game elements for individual Students. Snippets B1 and B2 mention gamification as a way to make learning more fun. This taps into students' intrinsic motivation, making the learning experience more interactive and engaging, potentially leading to deeper learning.

➤ *AI-powered chatbots and virtual assistants:* Chatbots provide round-the-clock support, answer questions, and guide students through complex tasks. They can even moderate discussions. Virtual assistants can automate administrative tasks and facilitate collaborative learning. These tools offer immediate support and can free up faculty time for more complex interactions with students. providing round-the-clock assistance and can help boost students' confidence. Snippets B1, B2, and S60 highlight the role of chatbots in providing instant responses and support. This can be especially helpful for students learning remotely or outside of traditional

instructional hours, offering a sense of constant availability and guidance [18].

➤ *AI for Automated Grading and Feedback:* AI tools can automate the grading of essays and assignments, providing immediate feedback to students. This allows for more frequent assessments and faster identification of areas for improvement. AI can also provide detailed feedback students [19]. However, the quality and nuances of the feedback provided by AI require careful consideration, and educators still need to be involved in the process. Snippets B2 and B3 mention automated scoring as an advantage of AI. This can significantly reduce the workload of educators, allowing them to focus on other aspects of teaching, as well as provide students with a quick analysis of their progress.

Innovative Teaching Methods Enhanced by AI

- *Self-paced and autonomous learning:* AI-powered personalized learning pathways allow students to learn at their own pace, focusing on areas where they need additional support. AI-powered chatbots and virtual assistants facilitate self-paced learning by providing support and on-demand information. AI can give students more control over their learning, fostering autonomy and self-regulation deeper understanding and greater engagement, taking into account individual learning preferences. Fragments B1 and S66 highlight the ability of AI to allow students to learn at their own pace. This takes into account individual learning speed and preferences, potentially leading to more effective and self-directed learning [20].

- *AI-enabled collaborative learning:* AI platforms can facilitate group formation, manage discussions, and provide intelligent moderation of collaborative projects. AI can even connect students around the world. AI-enhanced virtual environments enable students from different locations to collaborate in real-time. AI can improve collaborative learning by providing structure, support, and tools for communication and overcoming geographical barriers and promoting a rich exchange of ideas [21]. Snippets B1 and S60 mention that AI facilitates collaborative learning through chatbots and virtual assistants. This highlights the potential of AI to improve teamwork and communication skills, preparing students to work together.

- *Learning through interactive simulations and virtual reality:* AI-powered virtual reality simulations and environments provide immersive and interactive learning experiences, making complex concepts more tangible and understandable. Students can engage in hands-on learning and problem-solving in a safe and controlled virtual environment. These technologies can significantly increase engagement and understanding, especially for abstract or complex engineering concepts offer a bridge between theory and practice, allowing students to experiment without the need for physical resources. Fragments B1 and S66 emphasize the use of simulations and virtual reality to provide a hands-on experience. This is especially valuable in engineering, where the practical application of theory is essential, and AI can provide personalized guidance in these environments [22].

- *Personalized feedback and guidance:* AI systems provide immediate and personalized feedback on student performance, helping them identify areas for improvement. AI can also offer personalized recommendations for learning resources and learning strategies [23]. Timely and personalized feedback is critical to learning. AI can provide this at scale, supporting students' progress and motivation. This feedback can be tailored to individual learning styles. Several pieces highlight the role of AI in providing personalized feedback. This allows students to understand their strengths and weaknesses more effectively and adjust their learning strategies accordingly.

- *21st century skills development:* AI-based tools present complex tasks that require critical thinking, creativity, and problem-solving skills. AI can also improve communication and collaboration through teamwork simulations. Integrating AI into learning can help students develop the necessary skills for today's job market, where AI is becoming more prevalent. AI can also support creativity by offering new ideas and perspectives. B6 and S66 highlight the potential of AI to develop critical thinking and problem-solving skills. This is in line with the growing demand for these skills in the engineering profession, and AI can provide dynamic challenges to develop these abilities.

Analysis of the current state of AI integration in engineering education

Some studies indicate a relatively low level of actual use of AI tools among engineering students, despite familiarity with the concept [24]. For example, 70% of the students surveyed did not use AI tools such as ChatGPT. Other studies suggest the widespread adoption of AI technologies for

learning activities, with virtual assistants being particularly popular. In one study, 95.6% of students used AI in their educational activities. The level of AI integration is likely to vary significantly depending on the specific tools, engineering discipline, and educational institution. Generative AI is a recent phenomenon and its adoption is still evolving, there is a gap between awareness and actual integration into the learning process. The contradiction between B8 (low use of generative AI) and B5 (high use of AI in general) points to an ambiguous picture. This may be due to the different types of AI tools being considered (general AI vs. generative AI) or to the specific groups surveyed and the time frame of the research.

Generative AI, especially chatbots like ChatGPT, have received considerable attention in the recent literature. Intelligent learning systems and adaptive learning platforms are also often discussed. The current research landscape is heavily influenced by the emergence and rapid development of generative AI, leading to discussions about its risks and opportunities. However, established AIED technologies such as ITS and adaptive learning are still of great importance for personalized learning. Numerous passages mentioning ChatGPT and generative AI point to the current research focus on the implications of these new tools for assessment, teaching, and learning.

AI is being researched for personalized learning, automated assessment, creating training materials, improving simulations, and facilitating collaboration. Particular attention is paid to applications in civil, electrical and software engineering. For example, AI is being used in a civil engineering curriculum using knowledge-based expert systems. The versatility of AI allows it to be applied to various aspects of engineering education, from curriculum development and personalized learning to lab management and administrative tasks. The wide range of applications mentioned in the fragments (personalized learning, assessment, simulations, content creation, administrative tasks) demonstrates the great potential of AI in transforming various aspects of engineering education and even extends to areas such as library services and campus security.

Educators generally hold hopeful and positive views on the potential of AI in higher education, recognizing its potential to enhance learning and prepare students for an AI-integrated workplace. Students recognize the benefits of AI for understanding topics, solving problems, and helping them write papers. 60% of students find AI useful for understanding complex topics. However, there are concerns among both faculty and students about the ethical implications, the accuracy of AI-generated information, and the potential impact on critical thinking skills. Students also worry that AI may make them lazy and provide false information. Despite enthusiasm for AI's potential to increase efficiency and improve learning, there is also a healthy skepticism and awareness of potential drawbacks that need to be addressed through ethical principles and responsible integration strategies. The balance between positive views and concerns indicates cautious optimism in the academic community about AI in education. Teachers are optimistic, but also aware of the potential for abuse and negative impact on learning.

Prospects and forecasts for the development of AI in engineering education

✓ Hybrid learning models: The future likely lies in a combination of AI technologies and traditional training methods that leverage the strengths of both approaches. Hybrid models provide flexibility and scalability while maintaining personal interaction with educators. It is crucial to find the right balance between AI and human interaction. There seems to be a consensus on a blended approach, recognizing the value of both AI's capabilities in personalization and automation, and the important role of educators in leading, mentoring, and developing critical thinking. Several pieces clearly offer hybrid models as the way forward. This indicates a recognition that AI should complement rather than replace educators by creating a synergistic learning environment.

✓ Increased personalization and adaptability: AI will enable even more advanced, personalized learning programs that adapt to different learning styles and cultural backgrounds. Future AI systems need to become more sensitive to the diverse needs of students. Future AI systems could go beyond academic support to include emotional and social aspects. The trend towards personalization will continue, AI will become more subtle in understanding and responding to the individual needs of students, potentially leading to more effective and inclusive education. Fragments B3, B4, and B6

predict the emergence of increasingly complex AI systems capable of meeting diverse learning needs and even providing emotional and social support, creating a more holistic learning experience.

✓ **Emphasis on ethical considerations and responsible use:** There will be an increased focus on addressing ethical issues such as data privacy, algorithmic bias, and academic integrity. Ethical principles and a structured framework for AI integration will be required. Developing a framework for the ethical use and management of AI in education will be essential. As AI becomes more integrated, ethical considerations will come to the fore, requiring careful planning, policy development, and collaborative efforts among educators, policymakers, and technologists. The frequent mention of ethical considerations in various passages highlights the importance of addressing these issues early in order to implement AI in engineering education responsibly and equitably.

✓ **Developing new skills for teachers and students:** Educators will need training and professional development to effectively integrate AI tools into their teaching practice. The training of teachers in the field of AI will be extremely important. Students will need to develop skills in prompt engineering and critical evaluation of AI-generated content. Successful integration of AI requires a change in the skills of both teachers and students, which necessitates new curricula, pedagogical approaches, and a focus on the development of information literacy in the digital age. Fragments B3, B6, B7, and B10 emphasize the need to train educators to use AI effectively and to develop students' skills to interact and critically evaluate AI tools.

✓ **AGI and advanced AI capabilities:** Future advances in artificial general intelligence (AGI) have the potential to significantly improve learning environments by creating more interactive and responsive educational environments. AGI can act as both a teacher and a fellow student. AI can become an integral part of the professional toolkit of engineers, increasing productivity and efficiency in various industries. In the long term, better AI systems may emerge that are capable of offering dynamic, interdisciplinary learning environments and personalized learning trajectories, potentially leading to continuous adaptation and lifelong learning. Fragments B6 and S67 discuss the potential of AGI to create highly interactive and personalized learning programs, envisioning a transformative impact in the future by mimicking human-like cognitive abilities.

Key Trends and Research Areas

○ *Trend 1: Personalized and Adaptive Learning:* A strong emphasis on the use of AI to tailor the learning experience to students' individual needs and preferences.

○ *Trend 2: Generative AI Integration:* There is considerable research interest in the applications and implications of using generative AI tools such as ChatGPT in engineering education.

○ *Trend 3: Ethical Considerations:* Growing awareness and research into ethical issues related to AI in education, including bias, confidentiality, and academic integrity.

○ *Trend 4: AI Literacy Development:* Recognizing the need to equip both educators and students with the skills and knowledge to use AI tools effectively and ethically.

○ *Research Area 1: Effectiveness of AI Interventions:* Continued research on the impact of various AI tools and techniques on learning outcomes and student engagement.

○ *Research Area 2: Integration with existing pedagogical frameworks:* Exploring how AI can be effectively integrated with established learning theories and educational practices.

○ *Research Area 3: Long-term Impact of AI:* Long-term research to understand the long-term impact of AI integration on student skills, career readiness and learning attitudes.

○ *Research Area 4: Human-AI Collaboration:* Exploring ways to optimize collaboration between educators and AI systems to create the most effective learning environment.

Trends point to a future in which AI plays a significant role in personalizing learning and improving teaching, but ethical considerations and the need for proper training will be critical to successful and responsible adoption. Research is likely to focus on testing the effectiveness of various AI interventions and understanding their long-term impact.

A comparative analysis of approaches and results in the field of integrating AI into engineering education shows a variety of both methods used and the results obtained. Some research focuses on specific engineering disciplines, which allows for a deeper study of specific AI tools and pedagogical approaches that are most relevant to a given field. Other works take a more general approach,

looking at the integration of AI into engineering education in general. The use of various AI technologies, including intelligent tutoring systems (ITS), generative AI, adaptive learning platforms, and AI-based simulations, is highlighted. The choice of a particular technology is often driven by learning goals: ITS are focused on personalized learning, while generative AI is used to create content and provide assistance.

Research methodologies also vary, including literature reviews, case studies, student and faculty surveys, and the development of AI-based tools. Surveys assess the perceptions of students and teachers, while the development of tools demonstrates the practical application of AI in the educational process.

The results of using AI in engineering education are mostly positive, with increased student engagement, personalization of learning, and improved comprehension. However, some studies also point to problems such as the potential for plagiarism, over-reliance on AI, and the need for thorough scrutiny of AI-generated content. The results often depend on the specific AI tool and the strategy for its implementation. In general, approaches to integrating AI into engineering education are diverse, reflecting the versatility of both AI and engineering education. The reported results are mostly positive, but require careful interpretation and further evaluation of the effectiveness of various AI integration strategies in various fields of engineering.

The most frequently discussed challenges and obstacles associated with the successful integration of artificial intelligence into engineering education include:

- *Ethical considerations and academic integrity*: Issues related to plagiarism, cheating, and the potential for AI to undermine academic integrity raise significant concerns. AI's ability to generate human-like text raises questions about the authorship and authenticity of student papers.

- *Data privacy and security*: AI systems depend on data, which raises questions about the privacy and security of student information. The collection and use of student data by AI tools must comply with privacy regulations and ethical principles.

- *Algorithmic bias and fairness*: Concerns about the bias of AI algorithms and the potential for inequitable outcomes for certain groups of students. Bias in training data can cause AI systems to unfairly discriminate against certain demographics.

- *Infrastructural constraints and access*: The need for adequate technological infrastructure and equal access to AI tools and resources for all students and educational institutions. Disparities in access to technology can exacerbate existing inequalities in education.

- *Teacher training and professional development*: Lack of adequate training and support for educators to effectively integrate and use AI in their teaching activities. Many educators may not have the necessary knowledge to effectively use AI tools and need professional development opportunities.

- *Over-reliance on AI and reduced critical thinking*: Concerns that students may become over-reliant on AI, leading to a decrease in their critical thinking and problem-solving skills. Over-reliance on AI for tasks such as problem-solving and writing papers can make it difficult to develop important cognitive skills.

- *Accuracy and reliability of AI-generated content*: It is crucial to ensure the accuracy and reliability of the information and feedback provided by AI tools. AI models can sometimes generate incorrect or misleading information, which requires students to critically evaluate the results.

- *Resistance to change*: Potential resistance from both faculty and students to the adoption of new technologies and pedagogical approaches. Some educators may be reluctant to adopt AI due to concerns about its impact on their role or due to a lack of familiarity with the technology.

- *Upfront Implementation Costs*: The financial investment required to implement and use AI tools and platforms. The cost of AI software, hardware, and training can be a barrier for some educational institutions.

These challenges highlight the difficulty of integrating AI into engineering education. Addressing these obstacles will require a multifaceted approach, including policy changes, investment in infrastructure and training, ongoing dialogue within the academic community, and a focus on ethical considerations to ensure the fair and efficient use of AI.

CONCLUSION

In conclusion, the integration of artificial intelligence into engineering education has significant transformative potential, offering innovative teaching and learning methods that can personalize learning, increase engagement, and improve learning outcomes. The current state of integration is characterized by growing interest and experimentation with various AI technologies, especially generative AI and intelligent learning systems. Despite the promising prospects, there are a number of challenges and obstacles that need to be addressed to ensure the responsible and effective implementation of AI in engineering education. Ethical considerations, data privacy, algorithm bias, infrastructure limitations, teacher training, and potential over-dependency are just a few of the key issues that need to be carefully addressed. The future integration of AI into engineering education is likely to include hybrid learning models, increased personalization, and a continued emphasis on ethical principles. It is crucial for teachers and students to develop AI literacy and critical thinking skills in order to use these tools effectively. Continuing research into the efficacy of various AI interventions, their long-term impact, and ways to optimize human-AI collaboration for educational purposes will be critical to shaping the future of engineering education.

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Подлесний С. В., Єрємін М. В. Інтеграція штучного інтелекту в інженерну освіту: аналіз та перспективи.

У статті наведено огляд наукових публікацій за останні роки, присвячених всебічному дослідженню інтеграції штучного інтелекту (ШІ) у сферу інженерної освіти. Детально розглянуті інноваційні методи викладання та навчання, що активно використовують потенціал ШІ, такі як створення персоналізованих траєкторій навчання, застосування інтелектуальних навчальних систем для адаптивної взаємодії, використання симуляцій та віртуальних середовищ для практичного досвіду, впровадження гейміфікації для підвищення залученості та автоматизована оцінка для ефективної Ретельно проаналізовані інноваційні методи навчання, які значно удосконалилися завдяки інтеграції ШІ, включаючи розвиток самостійного та автономного навчання, розширення можливостей спільного навчання, застосування інтерактивних симуляцій та віртуальної реальності для глибокого занурення, надання персоналізованого зворотного зв'язку та керівництва, а також інтеграцію до навчального процесу. Наведено поглиблений аналіз поточного стану інтеграції ШІ в інженерну освіту, що охоплює рівні фактичного впровадження різних інструментів ШІ, основний акцент на конкретних передових технологіях, різноманітні галузі застосування ШІ в освітньому процесі та сприйняття як викладачів, так і студентів щодо переваг та потенційних проблем. Докладно висвітлено перспективи та прогнози подальшого розвитку ШІ в інженерній освіті, включаючи очікуване поширення гібридних моделей навчання, подальше поглиблення персоналізації освітніх програм, зростаючу увагу до етичних аспектів та відповідального використання ШІ, а також необхідність розвитку нових компетенцій у викладачів та студентів. Виявлено ключові тенденції та багатообіцяючі напрями подальших досліджень у цій галузі, а також докладно розглянуто основні проблеми та потенційні перешкоди, які можуть виникнути на шляху успішної інтеграції ШІ до інженерної освіти.

Ключові слова: штучний інтелект, інженерна освіта, інноваційні методи викладання, інноваційні методи навчання, персоналізоване навчання, адаптивні системи, інтелектуальні системи, генеративний ШІ, аналіз, перспективи..

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