B. Badalov, P. Movsumova,
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RT&A, Special Issue No. 7 (83),
Volume 20, May 2025

THE ROLE OF ARTIFICIAL INTELLIGENCE IN ENGINEERING STUDIES: A COMPARATIVE PERSPECTIVE FROM GLOBAL UNIVERSITIES AND AZERBAIJAN TECHNICAL UNIVERSITY

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Abstract

The advance of AI creates a field for innovation, efficiency, and creativity in many fields, not passing beyond engineering education. This study examines the integration of AI technologies into engineering curricula, highlighting practices at globally leading universities, including Stanford University, the Technical University of Munich (TUM), and the National University of Singapore (NUS), and comparing them with initiatives undertaken at Azerbaijan Technical University (AzTU). Using the narrative review approach, the article analyzes the role of AI in modeling, virtual laboratories, generative design and personalized learning. In addition, it discusses the critically important skills that modern engineers must acquire, and considers the ethical issues associated with the implementation of AI. The results show that although AI significantly enhances the educational experience and expands students' technical skills, strategic planning and oversight are critical to its evaluation. The article concludes with recommendations for future AI advocates in engineering education, particularly in new academic contexts.

Keywords: Artificial intelligence, engineering education, higher education, simulation, personalized learning, comparative study, digital technology, ethical AI

I. Introduction

In a rapidly evolving technological landscape, artificial intelligence (AI) is emerging as a transformative force, reshaping educational paradigms across sectors, with engineering being a particular focus. As a discipline focused on innovation, precision, and problem solving, engineering education can benefit greatly from the integration of AI. The introduction of intelligent technologies promises to facilitate more effective teaching methods, personalized educational trajectories and increased student engagement. Leading global institutions, from MIT to Stanford University, have quickly adopted AI-powered strategies, giving students access to cutting-edge tools and techniques that will make them resilient to the digital future.

The AI's role in education is versatile, and recent research increasingly highlights its reframing on engineering curricula. For example, Alimisis highlights how AI-based robotics education enhances critical thinking, problem solving, and creativity among engineering students, particularly in disciplines such as robotics and mechatronics [1].

Similarly, Khan et al. note that integrating AI into civil engineering technology programs not only enhances students' understanding of predictive maintenance concepts but also greatly enriches their training in smart city design by providing tools to address such urban challenges [14]. In turn, the study by Saldivar et al. [19]. demonstrates how the application of AI in electrical engineering – in particular the use of intelligent tutoring systems and adaptive educational platforms – contributes to improving learning outcomes by providing personalized support. Real-time feedback creates a more responsive and engaging learning environment with the help of this systematic approach.

According to a systematic review by Zawacki-Richter et al. there is compelling evidence that artificial intelligence technologies, including machine learning, natural language processing, and data analytics, are rapidly picking up steam in personalized learning environments, particularly in STEM disciplines [20].

This shift to AI-powered education not only improves the efficiency and effectiveness of teaching, but also allows for a more personalized approach to learning that takes into account students' different backgrounds and learning styles. Technology-enhanced learning and quantitative prediction can assist to explore gaps in students' knowledge, allowing teachers to actively intervene and adapt educational content accordingly. These AI tools are really important in engineering studies which mostly focuses on multifaced diagnostic and continuous innovation.

Furthermore, the future possibilities of AI in science and technology education exceed educational institutions. As industry demands continue to change, university curricula are increasingly integrating with AI technologies to ensure they align with current technological advances and societal needs, thereby equipping graduates with the competencies needed to succeed in an increasingly digital and automated world. The continual integration of AI tools into education also provides a floor for all students without any diversity. With AI tools they gain equity regardless of geographical location or socio-economic background, with high-quality learning experiences.

Succinctly, AI is balanced to reform engineering education by the quality and equity enhancement, encouraging creativity, and equipping students with the skills needed to manage the complexities of today's innovative environment. As educational institutions continue to leverage these advances, the opportunities for using AI at the forefront of engineering education become immense and inspiring.

II. Methodology

This study adopts a non-systematic comparative review approach to examine the integration of AI in engineering education across four universities: Stanford University, Technical University of Munich (TUM), National University of Singapore (NUS), and Azerbaijan Technical University (AzTU). Data were collected from academic literature, institutional reports, and publicly available documents, focusing on AI applications in engineering curricula, including adaptive learning systems, virtual labs, and AI-driven simulations.

A qualitative thematic analysis was employed to identify key trends, challenges, and opportunities in AI integration across these institutions. The analysis also addressed ethical considerations, such as algorithmic bias and data privacy, and explored the role of AI in preparing students for the digital future of engineering. The study also considered the varying institutional capacities and approaches, particularly in emerging economies.

III. Comparative Analysis

The fusion of neural network to education system created a paramount movement in last decades. With the advance of AI into the engineering disciplines which is always full of innovation and precision, a great deal of transformative pedagogical approaches was made. Aligning with industry many leading universities are actively embedding AI-driven methods into their curricula

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in order to prepare graduates for increasingly digital and automated industries. However, these experiences are not the same for every region, they can vary across educational systems. This paper aims to explore the role of AI in engineering studies by examining experiences at Stanford University, TUM, NUS, and Azerbaijan Technical University (AzTU), offering insights and recommendations for future development. This study uses a non-systematic review integrating insights from academic literature, institutional documents and personal experiences of different universities. AI applications in engineering programs, including modeling tools, virtual labs, generative design, and personalized learning environments are in the spotlight of data collection.

Stanford University has been a pioneer in the implementation of AI in engineering education. Through programs such as the "Design Thinking AI Labs" and "AI for Mechanical Innovation", the university is harnessing the power of AI to facilitate advanced computer simulation, predictive modeling, and advanced industrial techniques. The goal of these initiatives is to provide students with the tools and frameworks needed to solve real-world engineering problems in a highly automated world. [13].

At TUM, the integration of AI into engineering is deeply interdisciplinary, fostering innovation through its Center for Digital Technology and Management (CDTM), which blends AI with entrepreneurial skills, particularly in the domains of aerospace and robotics. This emphasis on combining technical knowledge with business acumen prepares students for success in high-tech industries [4]. The university has introduced AI-powered simulation labs, especially for smart energy systems and sustainable design projects. Additionally, students participate in hands-on workshops and research projects focused on robotics and machine learning, equipping them with practical skills essential for the modern engineering landscape.

AI in engineering, particularly in urban systems and civil engineering is a paramount movement in the National University of Singapore (NUS). The use of AI-driven simulations to predict and model urban growth and environmental impacts, supporting the broader goal of creating smarter, more sustainable cities is called the "Smart Nation Initiative" [7].

Artificial intelligence is being increasingly integrated into engineering education and research to foster innovation and improve learning outcomes at Azerbaijan Technical University (AzTU). Departments such as Computer Engineering and Automation and Control Systems offer AI-focused courses, while specialized laboratories support projects in machine learning, robotics, and smart automation [3]. AzTU collaborates with industry partners to incorporate real-world AI applications into student projects, enhancing practical skills [2]. Research initiatives, supported by national and international grants, focus on smart manufacturing, predictive maintenance, and intelligent infrastructure development (AzTU, 2024). Additionally, Smart Campus projects apply AI in areas such as energy management, campus security, and digital services, contributing to a more sustainable and efficient learning environment [17]. Recognizing the ethical implications of AI, AzTU is embedding AI ethics, fairness, and transparency into its engineering curricula, aiming to develop graduates who are both technically skilled and socially responsible [2].

Table: *Here is a comparative overview of AI integration in engineering education at different universities*

University	AI Applications in Engineering Education	Notable Initiatives
Stanford University	AI in mechanical design, intelligent systems	Design Thinking AI Labs, AI for Mechanical Innovation program
Technical University of Munich (TUM)	AI-enhanced aerospace simulations, robotics	TUM Center for Digital Technology and Management (CDTM)
National University of Singapore (NUS)	Smart urban systems, machine learning in civil and environmental engineering	Smart Nation Initiative, AI for Smart Cities program

Azerbaijan Technical University (AzTU)	Simulation software, robotics, sustainable design using AI	Establishment of AI-based research projects in smart energy and sustainability

AI offers transformative benefits for engineering education, including enhanced simulation capabilities, access to virtual laboratories, and opportunities for personalized learning experiences. Despite the growing integration of AI, emerging economies continue to face challenges such as inadequate infrastructure, imperfect teacher training, ethical issues, and difficulties in adapting curricula. All of these require targeted solutions. AzTU's initiatives demonstrate promising progress but highlight the need for sustained investment, international collaboration, and strategic capacity building. To ensure responsible AI use ethical considerations such as algorithmic transparency, data privacy, and bias, must be incorporated into engineering curricula [9] [12]. In order to prepare engineers for future challenges the development of critical thinking, creativity, and interdisciplinary knowledge have to be considered carefully before the implementation [18] [21].

IV. Challenges and Ethical Concerns

On the one hand AI brings its benefits for change, on the other hand the integration of AI into engineering education presents several complex challenges. One significant issue is algorithmic bias, where AI systems may reinforce existing inequalities in learning opportunities or outcomes if their training data is unbalanced or non-representative [12]. Data privacy is another critical concern, as AI often requires access to extensive datasets containing personal, academic, and behavioral information, raising ethical questions about consent, security, and responsible data stewardship [9]. Moreover, many AI models function as "black boxes," with decision-making processes that are difficult for educators and students to interpret or contest, undermining transparency and trust [8]. Accountability also becomes blurred when AI-driven systems influence critical educational outcomes, necessitating clear frameworks to assign responsibility among software developers, faculty members, and institutional policymakers [20]. Additionally, there is a growing risk of over-reliance on AI tools, which may discourage students from developing essential cognitive skills such as critical thinking, problem-solving, and independent research, if these tools are used uncritically or excessively.

Accessibility remains a persistent issue; resource-constrained institutions, particularly in developing regions, may face difficulties in acquiring and maintaining advanced AI infrastructure, thereby exacerbating global educational inequalities [11]. Beyond infrastructural challenges, cultural and linguistic biases embedded in AI systems can disadvantage non-dominant language speakers and diverse learner populations. Furthermore, embedding AI ethics education into engineering curricula is increasingly recognized as essential to prepare future engineers to anticipate, mitigate, and respond to ethical dilemmas posed by intelligent systems [12]. Lastly, ongoing stakeholder engagement — involving students, educators, technologists, and ethicists — is crucial to ensuring that AI deployment in education remains aligned with human-centered values, promoting inclusivity, fairness, and social responsibility.

V. Future Trends in AI and Engineering Education

Looking ahead, several key trends are likely to define the next decade of AI-driven engineering education. First, adaptive learning platforms powered by AI will become more sophisticated, offering customized learning pathways based on individual performance, learning styles, and personal interests [15]. These systems will dynamically adjust content and pacing, optimizing educational experiences to meet the diverse needs of students. Second, AI-enhanced virtual labs and simulations will provide students with more opportunities to experiment in risk-free, immersive

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environments, fostering creativity and problem-solving skills without the constraints of physical resources or safety concerns [10]. These tools will be particularly beneficial in engineering disciplines like robotics, automation, and aerospace, where physical testing can be costly and dangerous.

Furthermore, AI will likely play a crucial role in continuous curriculum updates, ensuring that engineering programs stay aligned with industry demands in real time [5]. By leveraging data from various sources — including industry trends, academic performance, and evolving technologies — AI systems will help educational institutions rapidly adapt their curricula, keeping pace with the ever-changing needs of the job market. This real-time responsiveness will enhance the relevance of engineering education and improve the employability of graduates.

Ethical AI education will also become a core component of engineering programs, ensuring that future engineers are not only technologically proficient but also socially responsible [12]. As AI technologies evolve, their applications raise important societal concerns, such as fairness, transparency, and accountability. As a result, curricula will increasingly focus on teaching ethical frameworks and decision-making processes for AI deployment, enabling students to navigate complex moral issues in their future careers.

AI is poised to redefine engineering education, fostering greater creativity, precision, and interdisciplinary collaboration. While leading universities such as MIT and Stanford demonstrate the vast possibilities AI offers, institutions like AzTU are making impressive advancements despite resource constraints. Future endeavors should focus on:

• Expanding AI-focused curricula across engineering disciplines to ensure a broader understanding of AI's potential applications in fields such as civil, mechanical, electrical, and environmental engineering.

• Strengthening capacity building projects that equip educators with the skills needed to integrate AI into academic and empirical approaches.

• Encouraging interdisciplinary research initiatives that combine AI with other advanced technologies such as biotechnology, nanotechnology and environmental sustainability to address complex problems of global concern.

• Create a comprehensive ethical framework for AI in education programs to ensure the sustainable design, implementation, and governance of AI technologies in real-world engineering applications.

Moreover, AI will enable universities to develop more effective and personalized learning assessment systems, providing students with real-time feedback and recommendations to enhance their academic progress [6]. These AI-driven assessments could help identify learning gaps early, offering timely interventions to improve student outcomes. However, challenges related to data privacy, security, and algorithmic bias will need to be carefully managed to avoid unintended consequences.

Further analysis should examine the lasting impact of AI integration on learning outcomes, focusing on how AI tools impact not only technical knowledge but also the development of critical reflection, ingenuity, and interpersonal skills. Empirical research using grounded theory approach will be crucial in evaluating the effectiveness of AI-powered learning environments and curriculum innovations in diverse academic contexts.

VI. Conclusion

The integration of artificial intelligence (AI) into engineering education has brought about transformative changes across various institutions, offering new opportunities for enhancing teaching, learning, and real-world applications. Experiences of the institutions like Stanford University, Technical University of Munich (TUM), National University of Singapore (NUS), and Azerbaijan Technical University (AzTU) are at the forefront of utilizing AI to prepare students for

the rapidly evolving engineering landscape. By incorporating AI-powered tools, simulations, and interdisciplinary projects, these universities are equipping students with the skills needed to address the complex challenges of the modern world.

However, while the potential of AI in education is vast, several challenges must be addressed to fully realize its benefits. Issues such as algorithmic bias, data privacy concerns, and the need for better infrastructure and teacher training remain critical obstacles, particularly for universities in developing regions. Institutions like Stanford and TUM, with their established resources and infrastructure, are better positioned to navigate these challenges, while universities like AzTU are making progress but require further investment and capacity-building efforts.

Looking ahead, the future of AI in engineering education holds great promise, particularly in areas like personalized learning, interdisciplinary collaboration, and real-world applications. As AI continues to evolve, educational institutions will need to adapt their curricula, invest in state-of-the-art technologies, and focus on ethical considerations to ensure that AI serves as a force for good in preparing the next generation of engineers. Collaboration between institutions, industries, and governments will be key to overcoming existing challenges and ensuring that AI contributes to the development of a sustainable, innovative, and inclusive global engineering community.

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