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ARTIFICIAL INTELLIGENCE IN TEACHING PHYSICS AT HIGHER EDUCATION INSTITUTIONS

Murod Sodiqov
Researcher, Samarkand Medical University

Abulfayz Khazratov
Researcher, Samarkand Medical University

Abstract

This thesis examines the transformative role of artificial intelligence (AI) in teaching physics at higher education institutions. AI enhances personalized learning, supports simulation-based and experimental education, enables real-time feedback, and facilitates collaborative and interdisciplinary learning. Intelligent tutoring systems, AI-driven data analysis tools, and generative language models help students develop conceptual understanding, mathematical reasoning, and practical skills. The thesis also discusses the role of educators, ethical considerations, and regional applications of AI, highlighting its potential to modernize physics education and prepare students for complex scientific and technological challenges in the 21st century.

Keywords: Artificial intelligence, physics education, higher education, personalized learning, simulation-based learning, intelligent tutoring systems, data analysis, collaborative learning, interdisciplinary education, educational technology

In recent years, artificial intelligence (AI) has emerged as a transformative force in higher education, reshaping traditional teaching and learning paradigms. Within the field of physics, which demands high levels of conceptual understanding, mathematical reasoning, and experimental precision, AI offers unprecedented opportunities to enhance both instruction and student engagement. Modern physics education not only requires mastery of theoretical principles and mathematical formalism but also the ability to analyze experimental data, simulate complex systems, and connect abstract models with real-world phenomena [1]. AI tools, including intelligent tutoring systems, generative language models, and simulation software, are increasingly enabling educators to address these multifaceted educational demands in innovative and effective ways.

One of the primary advantages of AI in physics education lies in its capacity to provide **personalized learning experiences**. Traditional lecture-based instruction often struggles to accommodate the diverse learning paces, prior knowledge, and cognitive styles of students [2]. AI-driven platforms, such as Physics-STAR or custom GPT-based tutoring systems, analyze students' problem-solving steps in real time and adjust content delivery accordingly. These platforms can identify common misconceptions in mechanics, electromagnetism, quantum physics, or thermodynamics and provide targeted explanations, hints, and exercises. As a result, students receive individualized guidance that enhances understanding and retention while fostering independent learning and critical thinking skills. Such adaptability is particularly valuable in higher education, where the complexity of physics concepts can overwhelm many learners.

AI also plays a crucial role in **experimental and laboratory-based learning [3]**. Modern physics curricula increasingly rely on laboratory exercises to develop analytical skills and practical competence. AI-powered tools assist students in designing experiments, processing data, and interpreting results. For example, AI-based systems can help students analyze pendulum oscillations, electrical circuit behaviors, or particle motion by applying machine learning algorithms to experimental datasets. Studies show that while traditional data analysis tools like spreadsheets provide quantitative insights, AI offers qualitative benefits, including reduced stress, increased motivation, and enhanced engagement with experimental material [4]. By enabling iterative learning and immediate feedback, AI supports a deeper understanding of experimental physics and promotes a more confident and reflective approach to scientific inquiry.

Moreover, AI facilitates **simulation-based learning**, allowing students to explore physical systems that may be impractical or impossible to observe directly. Through AI-driven simulations, learners can manipulate variables, model complex phenomena, and visualize abstract concepts, such as quantum wave functions, electromagnetic field interactions, or fluid dynamics, in an interactive environment. This not only reinforces theoretical understanding but also encourages exploratory learning, problem-solving, and creativity. By providing safe and flexible virtual laboratories, AI extends the scope of physics education beyond the constraints of physical resources, enabling students to engage with a wider range of scenarios and experiments [5].

In addition to supporting students directly, AI significantly **enhances the role of educators**. AI-powered platforms allow instructors to design inquiry-based learning experiences, generate challenging problem sets, and develop adaptive lesson plans aligned with students' proficiency levels. Custom GPT models tailored for physics educators, for example, can create lesson prompts, suggest simulations, and propose questions that stimulate critical thinking. This reduces the administrative burden on faculty, freeing them to focus on mentorship, conceptual explanations, and individualized guidance [6]. Consequently, AI serves as both a teaching assistant and a pedagogical amplifier, strengthening the overall quality and responsiveness of physics instruction.

Collaborative and interdisciplinary learning is another area where AI proves invaluable. Physics education often intersects with computer science, mathematics, engineering, and environmental science [7]. AI platforms facilitate group-based simulations, virtual laboratories, and collaborative problem-solving exercises, monitoring team dynamics and offering guidance to optimize collaboration. Students learn to integrate knowledge from multiple disciplines, communicate technical concepts effectively, and tackle complex, real-world problems. Such experiences prepare them not only for academic research but also for professional environments where interdisciplinary collaboration is essential.

However, the integration of AI in physics teaching also presents **challenges and ethical considerations**. Overreliance on AI tools may inhibit the development of fundamental problem-solving skills if students use AI-generated solutions without understanding underlying principles. Data privacy, algorithmic transparency, and intellectual property issues must be carefully managed. Educational institutions need to implement clear guidelines, training programs, and monitoring mechanisms to ensure AI supports, rather than undermines, the learning process. Furthermore, instructors must remain central in guiding students, interpreting AI outputs, and contextualizing complex concepts to maintain educational rigor and integrity [8].

In regions such as Uzbekistan, research on AI in physics education is growing, reflecting a broader global interest. Studies by Rasulov, Orinboyeva, Maxmudov, and others demonstrate how machine learning, neural networks, and AI-driven problem-solving systems can enhance students' understanding of physics concepts and improve academic performance [9]. Local scholars emphasize the integration of AI tools with project-based and interdisciplinary approaches, showing that AI can be effectively adapted to diverse educational contexts. These initiatives highlight both the potential of AI to transform physics education and the importance of context-specific implementation strategies [10].

In conclusion, the integration of artificial intelligence into physics education at higher education institutions represents a fundamental shift in both pedagogy and learning outcomes. AI provides unprecedented opportunities to tailor instruction to the individual needs of students, enabling personalized learning pathways that account for differences in prior knowledge, learning pace, and cognitive style. Intelligent tutoring systems, generative AI tools, and simulation software not only enhance conceptual understanding and problem-solving skills but also facilitate a deeper engagement with experimental and real-world phenomena. By offering immediate feedback, predictive hints, and adaptive content, AI empowers students to independently explore complex physics concepts and develop analytical thinking skills critical for academic and professional success.

In the regional context, particularly in countries like Uzbekistan, research demonstrates the potential of AI to modernize physics education, enhance student motivation, and improve academic performance. Local initiatives highlight the importance of context-specific implementation strategies, ensuring that AI tools are effectively integrated into curricula and adapted to local educational needs.

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