



Artificial Intelligence in Physics Education: Transforming Learning from Primary to University Level

Muhammad Shafiq¹, Muhammad Adnan Sami², Nudrat Bano³, Rida Bano⁴ & Muhammad Rashid⁵

¹Lecturer, Kohinoor Grammar School & College, Jaranwala Road Faisalabad, Punjab, Pakistan, 38000,

Email: mshafiq9996@gmail.com

²BS Scholar, University of Agriculture, Agriculture University Road, Faisalabad, Punjab, Pakistan, 38000,

Email: adnansamii.pk@gmail.com

³MS (SE), University of Agriculture, Agriculture University Road, Faisalabad, Punjab, Pakistan, 38000,

Email: nudrataliahmad@gmail.com

⁴MS (SE), University of Agriculture, Agriculture University Road, Faisalabad, Punjab, Pakistan, 38000,

Email: ridarana2020@gmail.com

⁵Senior Subject Specialist, Education Department, Government of the Punjab, Faisalabad, 38000, Punjab, Pakistan,

Email: rmuh003@aucklanduni.ac.nz, ORCID: <https://orcid.org/0009-0002-1257-7686>

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Corresponding Author:

Muhammad Rashid

Email:

rmuh003@aucklanduni.ac.nz



ABSTRACT

The teaching and learning in physics have undergone complete transformation through AI-driven intelligent tutoring systems adaptive learning stages and virtual labs that produce enhanced student involvement, interactive simulations and immediate feedback. The AI-powered Physics Education Technology (PhET) Interactive Simulations together with ChatGPT enables students to experiment with concepts by applying detailed explanations on complex physics theories to help abstract knowledge become more understandable. The deployment of AI resolves key educational obstacles since it delivers virtual labs alongside chatbots to make quality training more accessible for differential learners and resource-challenged students. Education integration of AI in physics faces major hurdles because of equity problems together with its expense burden and human resistance to adaptation and worries related to privacy of data and algorithmic discrimination. While AI instruments deliver better solutions for complex problems and enhanced understanding of concepts they do not reach scientific problem complexity levels which require human-like reasoning and heavy reliance on AI tools could hinder students' critical thinking abilities. Organizations receiving government financing along with training programs for teachers and ethical guidance must identify these challenges to establish high-quality physics education instruments. The supportive combination of AI with augmented reality and quantum computing enables educators and policymakers and researchers to collaborate for new educational breakthroughs. Responsible AI implementation enables physics education to achieve its goal of accessibility along with producing intriguing learning experiences which deliver effective 21st-century skill acquisition. The evolution emphasizes future progress in making traditional learning practices better through AI while developing careful implementation methods to help teacher reforms.

Introduction

Physics is the foundation on which all natural phenomena and technology advances lie. Many of these fields are important for our modern society's development and thus represent a critical scope on which the knowledge base for the future generation is going to be built. In the last century, physics education has experienced numerous changes that have shifted pedagogy from the traditional lecture-based and teacher-centered model to the more interactive, student-centered one. Moreover, overcrowded classes especially in public institutions, contribute a reasonable decline in education (Rashid et al., 2024). However, despite these advancements, challenges persisted: physics is complex without hands-on experience; students learn at different paces; personalized attention is often lacking; and, laboratory resource provision remains quite limited. Therefore, this gave rise to the infusion of technology, and particularly Artificial Intelligence (AI), into physics education as an innovative solution to the existing problems (C. Wieman et al., 2005).

The development and application of AI in education required decades of exploration and this carried on until the pre-October 2023 period where AI was incorporated into the education sector. AI was first defined in 1956, by John McCarthy (Zawacki-Richter et al., 2019), opening a new chapter in the field of technology. The history of AI in education (AIED) started as early as the mid-20th century with the creation of initial computer-based learning systems. Thus, the story of AI transitioning from a program-based instruction to an adaptive learning platform, made possible by machine learning (ML) and natural language processing (NLP) (Baker et al., 2009), and data analytics.

AI also includes designing systems that mimic human intelligence. These systems involve methods like ML, natural language processing, or expert systems (Mahligawati et al., 2023). The field of AI wasn't fully developed or integrated into education until years of research and exploration culminated before October 2023. The first definition of AI was introduced in 1956, by John McCarthy (Zawacki-Richter et al., 2019), thus marking the start of a new epoch in technology. The history of AI in education (AIED) dates back more than a single computer-based training systems were developed during mid of 20th century. The evolution of AI from programmed inclusive instruction to adaptive learning platform, supported by ML and natural language processing (NLP) (Baker et al., 2009), and data analytics, is chronicled in this narrative.

In the field of education, AI has proven to be nothing less than revolutionary, tackling age-old issues such as individualized learning, adaptive assessment, and maximizing efficiency. AI is not just a tool, but a game changer in academia as it not only fosters innovation, but better engage students with difficult topics like physics by accelerating their learning process. AI could help facilitate collaborative learning and the social aspects of online interaction through online discussions, joint activities, and peer assessment (Mahligawati et al., 2023). The initial uses of AI in education involved intelligent tutoring systems (ITS), which had a pronounced effect in enhancing student performance through custom feedback and adaptive learning paths (Koedinger et al., 1997). Research has shown that intelligent tutoring systems can reduce achievement gaps and improve overall student performance in STEM (Science, Technology, Engineering, and Mathematics) subjects (Kulik et al., 2016).

Table 1: Evolution of Artificial Intelligence in Education (AIED): Key Developments, Technologies, and Impacts

Time Period	Key Developments	Technologies	Impact/Outcomes	References
1950s-1960s	Early exploration of computers for personalized instruction	B.F. Skinner’s teaching machines	Laid the groundwork for AI-driven educational tools by providing immediate feedback	(Skinner, 1958)
1970s-1980s	Emergence of Intelligent Tutoring Systems (ITS).	SCHOLAR, Basic Instructional Program (BIP)	Simulated one-on-one tutoring, adapted to individual learners’ needs, and improved learning outcomes	(Ashley et al., 1982; Carbonell, 1970)
1990s-2000s	Rise of adaptive learning systems and data-driven approaches.	Carnegie Learning’s Cognitive Tutor, data mining, and learning analytics.	Personalized feedback, improved problem-solving support, and early identification of at-risk students.	(Baker et al., 2009; Koedinger et al., 1997)
2010s	Breakthroughs in machine learning (ML) and natural language processing (NLP).	IBM’s (International Business Machines) Watson Tutor, chatbots, automated essay scoring, virtual learning assistants.	Enabled real-time feedback, automated grading, and more sophisticated AI tools for education.	(Rajeshwari et al., 2020)
Recent Years	Expansion of AI capabilities in education, particularly in Science, Technology, Engineering, and Mathematics (STEM) fields.	Physics Education Technology (PhET) Interactive Simulations, virtual labs, AI-driven simulations, automated grading.	Enhanced engagement through interactive, visual, and gamified learning experiences.	(Koedinger et al., 1997)
COVID-19 Pandemic	Accelerated adoption of AI in education due to the shift to online learning.	Zoom’s AI-driven transcription, Google’s AI-based classroom management tools.	Bridged gaps in traditional education systems, improved accessibility, and supported remote learning.	(Pantelimon et al., 2021)

The Transformative Role of AI in Education

AI has transformed the traditional classroom by personalization of the learning experiences, instantaneous feedback, and immersion in simulations that shall boost attention of students to comprehending complicated concepts (Fadillah et al., 2024). Secondary school teachers, based in

the context of Malang, Indonesia, see the potential of AI for the personalization of learning experiences, automation of administrative tasks, and instant feedback to students (Rosi, 2024). AI also helps teachers in tasks like test-item generation and grading assistance (Feshchenko, 2024; Sperling et al., 2024), with teachers being able to spend more time on other instructional aspects. Emphasizing that the chat-GPT tool is valuable in creating specialized lesson plans, study guides, and assessment tests, secondary teachers of the future see it promoting workload and teaching efficiency (Fontao et al., 2024). In addition to teaching, the impact of AI would be felt in the assessment process by making extensive use of adaptive evaluations to vary the difficulty of a task based on a student's individual performance. Through this process, AI-enabled tools will be able to analyze a student's problem-solving procedure, identify typical misconceptions, and provide appropriately directed feedback. In the Andes Physics Tutoring System, for instance, the student step by step solution of a physics problem are continuously tracked and hints are instantiated to guide students on the path to the final solution (VanLehn, 2005). These systems are known to lead to better learning outcomes because they provide on-time and individual feedback (Tsai, 2014; Shute, 2008). The use of chatbots with self-studying physics also improves students' understanding by receiving real-time feedback and help, providing a more interactive learning experience (Duy et al., 2024; Yeadon et al., 2024). For example, research has been done on utilizing ChatGPT to improve high school students' grasp of physics through personalized learning environments (Alarbi et al., 2024; Ali et al.; Bessas et al.; Chapagain et al., 2024).

In developing countries like Pakistan, the education sector has witnessed a significant decline (A. Rashid et al., 2024), especially after COVID-19, due to prolonged school closures (A. Rashid et al., 2022), inadequate resources, and systemic challenges (M. Rashid et al., 2025). These setbacks highlight the urgent need for technological advancements, such as E-learning, AI-driven educational tools and quantum-enhanced computing, to bridge learning gaps and improve accessibility from primary to university levels specially in science education (Abbas et al., 2025).

The Emergence of AI in Physics Education

Physics education with the infusion of AI has been recognized as one of the best innovations in the war against some of the age-old problems in teaching and learning physics. AI in education, and specifically in physics education, has been widely studied, exploring its impact on learning outcomes, student engagement, and teaching effectiveness (Mahligawati et al., 2023). AI has redefined physics education across levels of primary, secondary and tertiary education - from intelligent tutoring systems to virtual labs to adaptive learning platforms. The use of AI for teaching physics remarkably goes back to the 1980s and 1990s when initial studies were conducted exploring its potential impact on enhancing the teaching and learning experience in the physics field via computer-based systems. Quantum computing, with its potential to handle exponential data growth efficiently, is emerging as a necessity for managing complex information systems (M. Rashid et al., 2013), particularly in physics and AI applications (Dunjko et al., 2018). During that time, earliest applications included the ITS that was designed as a one-on-one tutor for physics concepts. For example, Andes, an intelligent tutoring system developed in the late 1990s, provided individualized feedback and problem-solving support for students taking introductory physics. Research showed that the Andes system put students ahead of students taking the same courses in traditional classrooms (VanLehn et al., 2005).

The final years of the 20th century paved the way for the development of the first adaptive learning systems that roughly corresponded to the education of physics. They used AI algorithms to evaluate student results and automatically detected the need to adapt the level and type of teaching materials presented. For instance, through Carnegie Mellon University Cognitive Tutor Authoring

Tools (CTAT), some authors enabled real time interaction with a tutor who provided instant feedback and/or hints based on student inputs and fostered a more personalized learning environment (Aravind et al., 2017).

Table 2 AI Tools in Physics Education: Enhancing Engagement, Accessibility, and Understanding (Retrieved from (Verawati et al., 2024)

AI Tool	Functionality	Examples/Applications	Benefits
Knowledge-Based Systems	Organize complex information using knowledge graphs; provide personalized resources.	AI-powered evaluation systems	Tailors learning resources, identifies knowledge gaps, and promotes self-directed learning.
Interactive Simulations & Virtual Labs	Enable hands-on experimentation without physical labs; visualize abstract concepts.	TEALSim, Virtual labs in Moroccan schools	Improves engagement and understanding of complex topics like quantum mechanics.
AI-Based Language Models	Offer real-time tutoring and explanations; adapt to student needs.	ChatGPT	Provides personalized explanations, supports self-paced learning, and bridges gaps in instruction.
Machine Learning for Assessment	Automate grading and provide real-time feedback; identify areas for improvement.	AI-driven scoring systems	Reduces educator workload, ensures timely feedback, and improves learning outcomes.
Symbolic Regression Models	Derive equations for complex physics problems; enhance problem-solving skills.	Personalized learning tools	Helps students model equations and understand theoretical physics concepts.
Intelligent Virtual Tutors & Chatbots	Provide instant feedback and guidance; support self-directed learning.	Chatbots for self-study	Offers flexible, on-demand assistance and reduces isolation during self-study.

Machine Learning and its Role in Advancing Assessment of Students

ML has revolutionized the assessment process in physics education through automated, computerized grading systems. Such systems use ML algorithms to evaluate students' responses to physics problems, offering detailed feedback while minimizing the burden on educators. For example, an ML-based grading system developed by Piech et al. (2015) autonomously tells students what hints to take depending on their inferred problem-solving policies (Piech et al.). In this way, not only do timely assessments reach students, but more time can be given to personalized instruction for the teacher rather than paperwork. Recent advancements in NLP have minimized these systems further, enabling them to grade complex open-ended physics questions with high accuracy. Besides that, Kortemeyer (2023) investigated whether AI is capable of grading student problem solutions in introductory physics: A groundbreaking paper that

demonstrates that ML has the potential to optimize density scientific grading in enormous physics classes (Kortemeyer, 2023).

The 2010s marked a point of transition in the application of AI to physics education, especially with the emergence of ML and data analytics. This has already allowed AI tools to be created, specifically automated grading systems, predictive analytics, and personalization.” To address this need, researchers built ML algorithms capable of automatically grading physics problems and providing detailed feedback to students of physics, reducing the burden on educators and allowing students to receive faster feedback (Piech et al.). Another major contribution was using learning analytics to detect students at risk and to establish targeted interventions. Researchers trained predictive models on data generated by online learning platforms on courses and students and used this analysis to predict student performance and provide recommendations for personalized learning pathways (Shaun et al., 2014). These data driven methods are becoming useful in large-scale physics courses, where personal attention is quite challenging to provide.

Personalized Learning and Adaptive Systems

ML in physics education offers one of its most helpful features through the provision of personalized learning experiences. Adaptive learning systems powered by ML algorithms examine student performance data and generate appropriate educational material for students. As an example, Carnegie Learning's Cognitive Tutor uses machine learning to provide immediate feedback and personalized learning experiences, improving students' problem-solving capabilities and concept comprehension of physics (Alevan et al., 2009; Koedinger et al., 1997). These systems can dynamically determine knowledge gaps available to students and adjust the problems' levels of difficulty, maintaining student interest that is neither too easy nor too frustrating. Recent studies have explored the use of symbolic regression models in physics education, wherein ML is used to derive equations related to complex physics problems; the approach helps students model equations and gain insight into the mathematical relationships behind physical phenomena, thus bridging the gap between theoretical and practical applications (Shin et al., 2024).

Automated Grading and Assessment

AI systems are able to investigate student performance by the analysis of their strengths and weaknesses so that instruction is tailored to these differences in skill level that promote learning effectiveness (Feshchenko, 2024). Another study was done concerning higher secondary school and how AI was changing educational methodologies, focusing on areas of engagement and improvement, educator experiences on AI integration, larger considerations by ethics, and AI providing personalized learning experiences, wherein instruction is set up according to an individual student's needs of engagement, learning (Sarwar et al., 2024). Yongxian, Guozhu, and Ling (2020) introduced an AI-based evaluation and recommendation system based on knowledge graphs for high school physics learning that provided the student with specific resources according to their level of understanding and performance, thereby promoting individuality in learning (Yongxian et al., 2020). Such systems promote interactive and self-directed learning by linking topics and assessing students' knowledge gaps.

Predictive Analytics and Early Intervention

Predictive analytics and early intervention ML is also a predictive analytic method that has recently found home in the burgeoning field of physics education. Analyzing instrument data from online learning platforms has seen the development of machine-learning algorithms that can

predict student performance and identify at-risk students early during the course. Such early interventions may be personalized tutoring or additional reading material in which the student encounters difficulties which he or she may overcome before falling behind (Baker et al., 2009; Shaun et al., 2014). Some researchers have utilized ML models that predict achievement in physics among the listed students based on in-class assessment data, indicating the promise of such ML matrices to better learning outcomes based on insights driven by data (Santoso et al., 2023).

Virtual Labs and Interactive Simulations

ML is increasingly being integrated into virtual labs and simulations-which provide more hands-on experiences for learning to complex Physics concepts. PhET Interactive Simulations and TEALSim are just two platforms in which ML algorithms generally enable the creation of interactive, visual, and gamified learning experiences that heighten student engagement and understanding (Swandi et al., 2020; C. E. Wieman et al., 2008). Such tools then allow students to experiment with physical phenomena in an environment that seems less abstract. A more recent preprint introduced augmented physics, powered by ML creating interactive physics simulations from static diagrams. Such an innovative approach engages learners actively as they explore principles pertaining to physics (Gunturu et al., 2024).

Physics-Informed Machine Learning

Physics-Informed Machine Learning (PIML) provides new avenues of research and technology for education in physics. In essence, PIML uses traditional physics models intertwined with data-driven ML techniques to formulate more accurate predictions and simulations. For instance, Ma intensively reviewed the application of PIML within building energy modeling, arguing that integration would boost the accuracy and efficiency of energy simulations (Ma et al., 2025). Likewise, Quarteroni explored PIML in 2025 in the broad context of scientific research, showing how it can push the frontiers of physics education and research (Quarteroni et al., 2025).

The Role of AI in Modern Physics Education

AI is revolutionizing the teaching of physics via intelligent tutoring systems, adaptive learning platforms, and virtual simulations. These AI tools deliver a comprehensively personalized experience with the potential to adjust in accordance with the needs of the students, to their better understanding and retention. Studies have proven the viability of the AI features, which overstepped the traditional bounds of physics education, and enhanced students' interactions with physics-related items (Mahligawati et al., 2023). As in the more traditional physics class, such an approach would heavily rely on the student memorizing rules for manipulating equations, making it for some students difficult to relate to adding Jello together to a calculus equation. Though, AI-enabled simulations and virtual labs aim to solve this kind of problem by offering interactive experiences that assist student's helps to understand and experiment on principles of physics. AI-enabled virtual simulations add value to traditional learning and engagement offerings and promote critical thinking (Jing et al., 2023). One revolutionary application of AI to physics education is symbolic regression which implements learning algorithms to encode the solutions to the physics problems as equations relating the variables.

Zhu et al. (2024) designed for this purpose a personalized learning tool that allows the students to model the equations and connect them with the mathematical relations in physics. It increases their

computational skills and bridges the gap between the theoretical and practical applications (Zhu et al., 2024).

AI, along with other emergent technologies, stands to profoundly alter conventional educational systems through a shift toward more technology-based methodologies in teaching (Lee et al., 2021). This includes varying ways through which students are exposed to physics content. Through simulations powered by AI, students might explore and gather observations on the principles of physics in a controlled manner in an online environment, something that is virtually impossible in a conventional classroom. For example: platforms such as PhET Interactive Simulations, developed by the University of Colorado Boulder, allow students to investigate physical phenomena such as motion, electricity, and magnetism in a virtual space. Such technologies support active learning, which may even transform the students' attitude toward physics into viewing it as more accessible and less frightening (Lee et al., 2021). Research indicates that PhET simulations are very effective with respect to fostering student engagement and helping them grasp intervening concepts, especially since those concepts are difficult to visualize in their abstract mode (C. E. Wieman et al., 2008). Another simulation, the Technology-Enabled Active Learning Simulations (TEALSIm), enhances comprehension of intricate topics, such as quantum mechanics, by combining visual and interactive elements (Swandi et al., 2020).

AI-driven tutoring systems use adaptive learning paths and personalized feedback to simulate one-on-one interaction. Andes is an example of an ITS developed in the field of introductory physics courses and it utilizes cognitive modeling in guiding students through the problem-solving process. Based on the studies performed on Andes, there have been more impressive results of conceptual understanding and problem solving skills of the Andes users (VanLehn et al., 2005). Moreover, the rapid and targeted feedback that AI offers helps students rectify errors and enhance their problem-solving abilities (Mustofa et al., 2024). AI has increasingly transformed evaluation through rapid scoring and immediate primary feedback. AI language models, specifically ChatGPT, are indeed changing physics for the better by offering instant tutors, step-step reasoning based on its training, and dynamic clarifications based on student criticisms. As a support for independent learners, ChatGPT fills the gap between traditional instruction and autonomous learning through the benefits of an interactive dialogue (Liang et al., 2023). Other A.I. models, such as MathPix and GPT-4, can also facilitate the evaluation of physics problems, relieving the burden of many tasks from educators while giving students feedback immediately (Kortemeyer, 2023). AI tutors have been found to be able to tailor their interaction modes to the students' performances and preferences, making learning more efficient and accessible (Wang et al., 2013).

Table 3: Key Benefits of AI in Physics Education, Highlighting Tools and Their Impacts on Learning Outcomes

Benefit	Description	Examples/Tools	Impact/Outcome	References
Personalized Learning	AI tailors educational content to individual learners' needs, addressing varying levels of prior knowledge and learning styles.	Carnegie Learning's Cognitive Tutor for Physics, ChatGPT	Improved problem-solving skills, conceptual understanding, bridging gaps in knowledge, tailors support, reduces frustration, and enhances understanding	(Koedinger et al., 1997; Liang et al., 2023; Wang et al., 2013)

Visualization of Concepts	AI provides visual and interactive representations of abstract physics concepts, making them more accessible and engaging.	PhET Interactive Simulations (e.g., wave interference, electric fields).	Deeper conceptual understanding and increased engagement with complex topics.	(C. E. Wieman et al., 2008)
Problem-Solving Skills	AI tools break down complex problems into manageable steps and provide real-time feedback to guide students.	Andes (intelligent tutoring system).	Builds confidence, proficiency, and independent problem-solving abilities.	(VanLehn et al., 2005)
Increased Engagement	AI-powered tools make learning interactive and enjoyable, motivating students to invest time in understanding concepts.	PhET Interactive Simulations, gamified learning platforms.	Improved learning outcomes due to higher student engagement and interest.	(C. E. Wieman et al., 2008)
Enhanced Engagement	AI tools create interactive, hands-on learning experiences.	TEALSIm, ITS	Improves comprehension, encourages active learning, and provides personalized feedback.	(Sánchez-Guzmán et al., 2010; Swandi et al., 2020)
Increased Accessibility	AI makes physics education accessible to students in remote or under-resourced areas.	Virtual labs, AI chatbots	Democratizes access to practical learning and supports self-paced study.	(Duy et al., 2024; Menchafou et al., 2024)
Efficient Assessment	AI automates grading and provides real-time, targeted feedback.	Machine learning-based scoring systems	Reduces educator workload, ensures consistent feedback, and improves learning outcomes.	(Kurniawan et al., 2024)

AI in Physics Education across Different Educational Levels

AI in Primary Level Physics Education

The act of teaching primary-level physics has been transformed forever by the introduction of AI to truly engage the young ones, foment the spirit of curiosity, and introduce the very foundations of scientific reasoning to the learner's mind. The realm of early physics education is benefiting from the infusion of AI tools, gamified parody composition, and interactive platforms. IBM, International Business Machines Corporation, came up with Watson Tutor-a real-time question-

and-answer bot for a more personalized teaching that piqued curiosity (Afzal et al., 2019). Watson has also served as a great tool for quickly analyzing vast amounts of student responses and thereby assisting teachers in organizing student responses according to what they mean (Campbell et al., 2024). Personalized tools which adapt according to the learning pace of each child are being introduced so that no child is left behind. Furthermore, in this interactive storytelling, AI-generated fairy tales are spiced with physics concepts like gravity and motion for more engagement and understanding. This way, using natural language processing, personalized learning experiences making complex ideas interesting and obtainable are generated, culminating in interest and retention of knowledge by the children (Kotsis, 2024).

The role of inclusive early childhood education is gaining attention, as it lays the foundation for lifelong learning and cognitive development (Qureshi et al., 2024). The young generation is more into computer based set up. So there is a dire need to implement Ai driven computer tools for the young generation stepping into the education system.

AI in Secondary Level Physics Education

The teaching of physics at secondary school has reached the level of abstraction and complexity requiring knowledge from students that will be advanced and in some way applicable to real-life situations. Therefore, AI appeared as a potential cure-all to meet these demands by providing personalized education solutions, enabling hand-on experimentation through virtual labs, and offering intelligent means of assessment and feedback. AI will revolutionize and propel the traditional method of teaching far ahead, with adaptive learning, real-time feedback, and immersive simulations that make learning intricate content easier and more engaging (Sperling et al., 2024) For some parts of secondary-level physics education with few traditional resources available to them, the AI-based virtual labs and simulations quickly became indispensable tools. There is literature that documents the efficacy of the virtual format for performing the experiments, and it has helped improve physics learning in many contexts, especially in low-resource settings. After immersing themselves in simulations, the students learn how to overcome certain difficulties in understanding complex physics principles. The PhET Interactive Simulations and Labster provide opportunities for students to perform experiments in a virtual setting so that they can explore concepts like wave interference, projectile motion, and electric circuits (C. E. Wieman et al., 2008). By exploiting the excellently accurate virtual lab capabilities it has to offer, this will enable students to enhance their problem-solving skills in physics and allows them to leave the lab with richer experiences. Studies indicate that, when considering conceptual understanding as well as practical skill development, virtual labs contribute significantly to students and provide a worthy supplement to traditional laboratory experiments (De Jong et al., 2013). Robotics kits armed with AI such as SPIKE Prime from LEGO Education allow children to assemble and program robots while learning such basic principles of physics as force, motion, and energy. Such hands-on experiences not only motivate students to learn but also develop critical thinking and problem-solving skills (Petrovič).

AI in University-Level Physics Education

The focus of ongoing research is on the development of integrated AI-enabled applications of online learning endowed with gamification to improve the teaching-learning of physics at the university level. Essentially, these tools aim to change students' perceptions of physics from dull and hard to fun and enjoyable through active engagement by obtaining interactivity with physics. Through integrating the AI-enabled features of immediate feedback along with gamification motivational elements such as points, badges, and leaderboards, these platforms strengthen

engagement and foster a better perception of physics at the foundational level (Cheah, 2021). A study at university level found that using ChatGPT, combined with gamification approaches for physics learning, outperformed traditional classes by yielding better academic improvement along with increased motivation. This AI incorporated gamification in providing personalized feedback through ChatGPT, offering real-time support specifically tailored to the individual's needs while also adding the enhancement of interactive components, including challenges, quizzes, or simulations, through such AI-driven explanations and guidance on request. Meanwhile, using AI, the system tends to change the difficulty of challenges according to how far each student has progressed to maximize engagement without causing overwhelm (Beltazar-Clemente et al., 2024).

Challenges and Limitations of AI in Physics Education

In terms of the integration of AI into physics education, there are many challenges that will significantly impair its effectiveness. One of the issues here regards the lack of structured ways of infusing AI into the curricular practice. There is need for clearer strategies on how to incorporate AI tools and traditional teaching methods so that meaningful improvements are made in education (Mustofa et al., 2024). While using tools like ChatGPT in support of problem-solving, Ding (2023) notes that students sometimes question the accuracy, which creates mistrust in AI as a resource for learning. Such shyness might greatly restrain the widespread use of AI in education, where consistency is of utmost importance (Ding et al., 2023). Furthermore, though AI simulations and adaptive learning platforms stand to personalize education, their capacity to accommodate varying learning styles is still debatable. More studies should be conducted to enhance AI adaptiveness to ensure it will incorporate varied student needs. Such targeted studies will go a long way to enhancing the reliability, effectiveness, and orderly introduction of AI in physics education (Liu et al., 2021).

Future Directions and Opportunities for AI in Physics Education

The adoption of AI-based physics education is still in its burgeoning stages, with tremendous opportunities for expansion and development. Researchers as well as educators are always in pursuit to resolve present restrictions and employ new technologies in order to uplift teaching-learning paradigms. We need government-funded commitments to ensuring connectivity and devices for schools and NGO partnerships to ensure low-cost AI toy development. More, serious work must underwrite access to-quality AI-in-an-educational process for all students, regardless of socioeconomic status (Warschauer et al. 2010). Policymakers and educators must step up and clarify data collection, storage and usage. That includes implementing strong encryption protocols, obtaining informed consent from students and parents, and being transparent about how data is used. Additionally, numerous publications have called attention to the necessity of implementing urgent and pragmatic measures to safeguard student data against potential risks associated with the proliferation of AI technologies, thus outlining approaches to bolster data privacy in the realm of education (Ismail et al., 2025). Preventing security and ethical issues necessitates the implementation of stronger data governance policies within the services of privacy, accountability, and fairness pertaining to AI-based physics education (Duy et al., 2024).

AI can therefore originate personalized learning pathways that align with the needs of each learner and provides each learner the support that they need to succeed, such as in the case of the ASSISTments platform that has used AI personalized feedback and adaptive learning pathways of students in STEM-content classes (Heffernan et al., 2014). Furthermore, similar to the ITS example, ITS will help provide example-tracing tutors through the tracing of the steps the

individual undertakes in completing their problem-solving endeavors (Aleven et al., 2009). When AI and emergent technologies like Augmented reality (AR), Virtual Reality (VR), Quantum Computing are intertwined together, we get more immersive and interactive learning experiences. AR is capable of high efficiency in STEM education, including physics, as it provides a realistic context for abstract concepts in an engaging manner for the students (Ibáñez et al., 2018) and as a result, also contributes positively to learning outcomes in STEM subjects (Radu, 2014).

For education's investment in AI to work, it is unwarranted to wish teachers to be prepared, motivated, capable, and engaging it deeply, all without help from their professional learning communities. This involves comprehensive training and professional development programs that help educators understand and effectively use AI tools (Holmes, 2019). Moreover, policy makers should ascribe priority in integrating AI into the educational strategy of the nation by providing adequate funding and mobilization of schools to integrate new technologies (Zawacki-Richter et al. 2019). Practice with new technologies for a teacher's professional growth requires intensive and sustained professional learning (Desimone et al., 2015). Research showed that when teachers underwent professional development training: the use of AI in their teaching practices was heavily emphasized; as a result, they felt confident doing so in their classes (Roshan et al., 2024).

AI integration should entail professional development designed according to the needs of educators. A pre-survey to assess the teachers' understanding, skills, and attitudinal disposition regarding AI tools can help in developing worthwhile training programs. AI training should be hands-on to facilitate quick-on-the-ground applications in the classroom. Blended learning combines synchronous and asynchronous aspects for liberally supportive learning and trainer instruction. Training clips, webinars, and forums for discussion can supplement online training resources. This assures that teachers can assimilate the use of AI tools within the time frame set by their schedules (Bonk et al., 2012; Desimone et al., 2015). Schools and educational centers are in urgent and great need of allocating resources for efficient professional development that is brief but inclusive in scope when speaking of AI technologies. Teachers must receive information on how the adoption of AI will positively impact their vocation by decreasing the quantity of time spent upon administrative tasks in their jobs. In addition, the directives about the ethical concerns snowball upon data protection said regarding AI by the schools are of utmost priority to both the families and the teachers in lifting the fears associated with the use of this kind of technology (Roshan et al., 2024).

Conclusion

AI integration into physics education has showcased tremendous promise when looking at possible transformations of teaching and learning. AI tools, like adaptive learning platforms, intelligent tutoring systems, and virtual labs, have, indeed, brought about changes in relation to personalized learning experience, rendering them more engaging and effective: for example, platforms such as ChatGPT and Cognitive Tutor differentiate the instruction in accordance with students' individual needs; virtual labs, such as TEALSim, present hands-on opportunities to experience interaction and thus manifest intuition about the abstract concepts of physics, like quantum mechanics. Additionally, AI-driven chatbots and machine learning algorithms are aiding accessibility to students in rural or resource-poor areas by providing an independently paced learning opportunity with feedback in almost real time. Such advances help enhance student engagement and understanding, yet, at the same time, cut down the administrative burden on teachers and allow them to focus on personalized instruction. Unfortunately, there exist challenges of equitable access, data privacy, and the need for teacher training before AI can realize its full potential.

Policymakers have to invest in the infrastructure and write ethical guidelines; educators must accept these as complementary tools. By contrast, researchers need to investigate avenues whereby AI can be optimized to fit varied environments with high-quality learning outcomes and consider the long-range effects. Only in concert can these actors tap into the transformative power of AI and institute an all-embracing, engaging, and effective physics education that readies the students for the complex 21st-century challenges.

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