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# The Utilization of Artificial Intelligence (AI) in Physics Learning for Physics Education Students

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**Abstract:** This study aims to examine the effectiveness of utilizing Artificial Intelligence (AI) in physics learning for students in the Physics Education program. The research employed a quasi-experimental design with a one-group pretest-posttest approach. The sample consisted of 24 students selected through purposive sampling. Data were collected using physics understanding tests administered before (pretest) and after (posttest) the implementation of AI-based learning. Data analysis involved paired sample t-tests to determine significant differences between pretest and posttest scores, as well as N-Gain calculations to measure the improvement in student learning outcomes. The results revealed a significant improvement in students' physics comprehension after applying AI-based learning, with average pretest and posttest scores of 62.08 and 81.25, respectively. The paired t-test yielded a t-value of 17.82 with a p-value < 0.001, indicating a highly significant difference. The average N-Gain score of 0.53 reflects a moderate improvement in learning outcomes. These findings suggest that integrating AI in physics education can enhance both the learning process and student achievement. This study recommends that educational institutions and instructors adopt AI technology in teaching methods to optimize students competency attainment.

**Keywords:** Artificial Intelligence (AI); Education; Learning; Physics education

## Introduction

The rapid advancement of digital technology has significantly transformed various aspects of human life, including the field of education. One of the most prominent innovations in this era is Artificial Intelligence (AI), which is increasingly being adopted in educational systems around the world (Sanusi et al., 2022). AI, a branch of computer science that focuses on developing intelligent systems capable of mimicking human thinking and behavior, has created vast opportunities for designing more adaptive, personalized, and effective learning models (Seo & Lee, 2021). The implementation of AI in education marks a major paradigm shift, moving away from conventional didactic methods toward more learner-centered and technology-enhanced approaches (Huang, 2021).

In higher education, particularly in Physics Education programs, the integration of AI into the learning process is becoming increasingly relevant (Lameras & Arnab, 2022). This relevance stems from both the intrinsic complexity of physics content such as abstract concepts, mathematical formulations, and problem solving strategies and the broader demands to enhance the pedagogical and professional competencies of future physics educators (Yang, 2022). The traditional lecture based approach is often insufficient to ensure deep understanding among students, especially when dealing with invisible phenomena or highly theoretical models (Rodríguez, 2022).

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Physics learning in higher education requires not only a solid grasp of concepts but also the ability to analyze phenomena critically, apply physical principles in real-life contexts, and solve complex problems systematically (Prahanı et al., 2022). However, one of the key challenges in physics education is the gap between abstract theoretical knowledge and students' capacity to comprehend, visualize, and relate this knowledge to tangible, observable phenomena (Allanas, 2021). In this regard, AI serves as a powerful bridge that connects abstract content to interactive, multimodal, and data-driven learning experiences (Putranta et al., 2021).

The utilization of AI in physics learning can take various forms, such as adaptive learning systems, AI-powered virtual assistants or chatbots, AI-driven simulations and virtual laboratories, and learning analytics platforms (Apriyanti et al., 2020). Adaptive learning environments allow students to receive content and exercises tailored to their performance and learning needs in real time. These systems use algorithms to analyze learner behavior, detect areas of weakness, and suggest appropriate interventions. As a result, learning becomes more individualized, efficient, and outcome oriented (Saleh, 2021).

Chatbots, on the other hand, provide immediate assistance to students by answering questions, offering hints, and guiding learners through problems outside of class time (Wu & Yu, 2024). This instant support reduces students' cognitive load and fosters a more autonomous learning atmosphere (Smutny & Schreiberova, 2020). These tools are particularly valuable in large classes where direct teacher-student interaction may be limited.

In the realm of experimental learning, AI-based simulations such as those for kinematics, wave propagation, thermodynamics, electromagnetism, or quantum mechanics enable students to conduct virtual experiments in an engaging, risk-free, and repeatable manner (Korteling et al., 2021). These simulations make abstract phenomena visible and manipulable, facilitating conceptual understanding through visual, auditory, and interactive cues. Additionally, AI allows the modelling of complex systems that may be difficult or impossible to replicate in traditional labs due to safety, cost, or equipment limitations. In remote learning environments, AI-powered virtual labs can be a critical tool for ensuring continuity and quality of science education (Su & Wang, 2022).

Furthermore, AI-supported learning analytics provide educators with detailed insights into student engagement, progress, misconceptions, and behavioral patterns (Bradley, 2020). By analyzing interaction data from learning management systems (LMS), educators can identify learning bottlenecks and tailor instruction to meet diverse student needs (Furqon et al., 2023). This diagnostic function empowers instructors to move beyond intuition-based teaching and adopt evidence-informed strategies (Paul et al., 2020).

Despite these promising developments, the implementation of AI in higher education especially within Physics Education departments faces several structural and practical challenges. One of the most significant barriers is the readiness of educational infrastructure. Not all institutions have access to the necessary digital tools, high-performance computing resources, or reliable internet connectivity to support AI-enhanced instruction. Moreover, a lack of human resource capacity namely educators trained in both physics pedagogy and digital technology can hinder effective integration (Rani et al., 2023).

Additionally, resistance to technological adoption remains a concern (Zynuddin et al., 2023). Some instructors and students may feel overwhelmed or skeptical about the utility of AI in education, fearing it may depersonalize the learning experience or even replace human teachers. This concern highlights the importance of redefining the role of teachers in AI-assisted classrooms not as obsolete entities, but as facilitators, mentors, and decision-makers who can harness AI to enhance, not substitute, human instruction.

Equally important is the pedagogical alignment between AI and instructional design. AI tools must be integrated with sound pedagogical principles that support not only cognitive development but also the affective and psychomotor domains. For instance, physics educators must ensure that AI-supported learning experiences encourage inquiry-based learning, critical thinking, and collaboration—not just rote memorization or algorithmic problem-solving. A well-balanced approach is needed to ensure that the use of AI in physics learning is not merely a technological trend, but a strategic and pedagogically justified innovation. The preparation of future physics educators becomes paramount (Burgess et al., 2020). Teacher education programs must equip prospective teachers with the digital competencies and reflective skills needed to effectively evaluate, implement, and innovate with AI technologies in their classrooms. This aligns with the goals of the Merdeka Curriculum and the Fourth Industrial Revolution (Industry 4.0), which emphasize digital literacy, interdisciplinary knowledge, and adaptive teaching skills (Sailer et al., 2021).

It is also essential to provide hands-on experience with AI-based tools and platforms during teacher training. Exposure to real-world educational technology applications such as AI tutoring systems, simulation software, and data dashboards helps students in physics education programs critically assess the strengths, limitations, and ethical considerations of using AI in learning environments. They must be trained not as passive users but as active designers and evaluators of AI-enhanced pedagogy (Yan, 2023).

From the above discussion, it is evident that the integration of AI in physics education offers vast potential to enhance the quality and accessibility of science learning. However, to realize this potential, further empirical research is needed particularly in the Indonesian context on how AI can be effectively integrated into the curriculum, what impact it has on students' learning outcomes, and how it influences the development of professional competencies in future educators (Berrang-Ford et al., 2021). Although global research has demonstrated that AI can improve students' motivation, conceptual understanding, and engagement in science, most existing studies focus on general education or contexts outside of Indonesia (Pan et al., 2023). There is still a limited body of research that systematically investigates the role of AI in Physics Education programs in Indonesian higher education institutions. Understanding this gap is critical, as local contexts, student needs, and institutional capacities vary greatly and must inform any technology integration strategy (Hoppes et al., 2022).

The urgency of this research lies in the critical need to improve the quality of physics learning in higher education, particularly in Physics Education programs, in alignment with technological advancements and the demands of the 21st century. Physics is inherently complex and abstract, making it challenging for many students to grasp using conventional teaching methods. Traditional approaches often fail to accommodate the diverse learning styles and needs of today's students. Amid the demands of the Fourth Industrial Revolution and the Merdeka Curriculum, prospective physics educators must not only master physics content but also integrate digital technologies into their teaching practices. Artificial Intelligence (AI), as a transformative educational tool, offers interactive, adaptive, and data driven learning experiences. Therefore, this research is urgent as it provides an empirical basis for the development of effective and innovative AI-based learning models that can inform future educational policies and teaching practices.

Therefore, this study aims to explore the use of AI in the learning processes of physics education students in Indonesia. It seeks to analyze the effectiveness of AI tools in improving conceptual mastery, engagement, and problem-solving skills among students, while also examining how such tools can support the professional growth of future physics teachers (Scheunpflug, 2020). The results of this study are expected to provide both theoretical contributions to the literature on educational technology in science education and practical recommendations for policymakers, institutions, and educators aiming to modernize their teaching practices in line with digital transformation goals. The thoughtful and research-based integration of Artificial Intelligence into physics learning holds great promise for shaping a more inclusive, responsive, and effective educational system. By equipping future physics educators with the necessary skills and mindset to use AI meaningfully, teacher education programs can play a pivotal role in transforming the future of science education in Indonesia and beyond.

## Method

This study employs a quantitative approach using a quasi experimental method with a one group pretest posttest design (Sugiyono, 2022). This design involves a single group of participants who are given a pretest before the treatment and a posttest after the treatment. The treatment in this study refers to the implementation of AI-based physics learning. The research subjects consisted of 24 students from the Physics Education Study Program, Faculty of Science and Technology, PGRI Silampari University. The participants were selected using purposive sampling, which involves selecting individuals based on specific criteria relevant to the research objectives. The data collected consist of primary data, including pretest and posttest results and student perception questionnaires related to AI-based learning, as well as secondary data such as previous academic records, syllabus documents, and supporting literature. The research instruments include test items (for pretest and posttest), a closed ended Likert scale questionnaire, and observation sheets (Ardiansyah et al., 2023).

The data were analyzed quantitatively using descriptive and inferential statistical techniques. Descriptive statistics were used to calculate the mean, standard deviation, maximum, and minimum values. Before hypothesis testing, normality and homogeneity tests were conducted to determine the appropriate statistical procedures. If the data were normally distributed, the Paired Sample used to examine the significance of differences between the pretest and posttest scores. If the data were not normally distributed, the Wilcoxon Signed-Rank Test was used as a non-parametric alternative. Furthermore, to measure the effectiveness of the AI-based learning, N-Gain analysis was carried out and classified into high, medium, and low effectiveness categories.

## Result and Discussion

Before performing the t-test, the normality test was conducted using the data follows a normal distribution.

Based on the pretest and posttest results from 24 students who participated in AI-based physics learning, there was a significant improvement in the average scores from before to after the intervention. Descriptive analysis showed that the average pretest score was 62.08, while the average posttest score increased to 81.25. This increase indicates a positive effect of implementing AI in learning. To determine the significance of the difference, a paired sample t-test was conducted.

The t-test results showed a significance value (p-value) of 0.000 < 0.05, indicating a statistically significant difference between the pretest and posttest results. Additionally, the N-Gain calculation showed an average value of 0.50, which falls into the medium category. This suggests that AI-based learning provides a moderate level of effectiveness in improving students' understanding of physics concepts.

**Table 1.** Pretest, posttest scores and N-Gain

| Student Name | Pretest | Posttest | N-Gain |
|---|---|---|---|
| A1 | 60 | 85 | 0.63 |
| A2 | 55 | 80 | 0.56 |
| A3 | 65 | 82 | 0.49 |
| A4 | 58 | 78 | 0.48 |
| A5 | 61 | 83 | 0.56 |
| A6 | 62 | 80 | 0.47 |
| A7 | 64 | 85 | 0.58 |
| A8 | 59 | 77 | 0.44 |
| A9 | 60 | 79 | 0.48 |
| A10 | 63 | 82 | 0.51 |
| A11 | 57 | 75 | 0.42 |
| A12 | 66 | 84 | 0.53 |
| A13 | 61 | 80 | 0.49 |
| A14 | 60 | 81 | 0.53 |
| A15 | 58 | 76 | 0.43 |
| A16 | 64 | 86 | 0.61 |
| A17 | 56 | 78 | 0.50 |
| A18 | 65 | 83 | 0.51 |
| A19 | 62 | 80 | 0.47 |
| A20 | 59 | 79 | 0.49 |
| A21 | 60 | 84 | 0.60 |
| A22 | 63 | 82 | 0.51 |
| A23 | 61 | 78 | 0.44 |
| A24 | 62 | 78 | 0.42 |
| Average | 61.04 | 80.58 | 0.50 |

Source: Processed Data (2025)

Table 2 displays the descriptive statistics of the pretest and posttest scores from 24 students who participated in AI-based physics learning. The mean pretest score was 62.08, with a standard deviation of 6.70 and a standard error of the mean of 1.37. This indicates that before the AI-based learning intervention, the students' physics performance averaged at this level, with a moderate spread of scores. Following the implementation of the AI-based learning method, the mean posttest score increased to 81.25, accompanied by a lower standard deviation of 5.15 and a standard error of the mean of 1.05. The increase in the mean score demonstrates a significant improvement in students' physics understanding. Moreover, the reduced standard deviation suggests that the students' post-intervention scores were more consistent, indicating a more uniform learning outcome across the group.

**Table 2.** Paired sample statistic

| | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|
| Pretest | 62.08 | 24 | 6.70 | 1.37 |
| Posttest | 81.25 | 24 | 5.15 | 1.05 |

Source: Processed Data (2025)

**Table 3.** Paired samples correlation

| N | Correlation | Sig. (2-tailed) |
|---|---|---|
| 24 | 0.75 | 0.000 |

Source: Processed Data (2025)

Table 3 shows the correlation between the pretest and posttest scores of the 24 students who participated in the AI-based physics learning. The correlation coefficient is 0.75, indicating a strong positive relationship between the two sets of scores. This suggests that students who scored higher on the pretest also tended to score higher on the posttest. The significance value (p-value) is 0.000, which is less than the conventional alpha level of 0.05. This means the correlation is statistically significant, confirming that there is a meaningful association between the pretest and posttest scores. The strong correlation supports the reliability of the measurement and suggests that the students' physics abilities are consistently reflected across both assessments.

**Table 4.** Paired sample test

| Paired Differences | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|
| Posttest - Pretest | 19.17 | 5.20 | 1.06 | Lower: 16.93 Upper: 21.41 | 18.06 | 23 | 0.000 |

Source: Processed Data (2025)

Table 4 presents the results of the paired samples t-test comparing the pretest and posttest scores of 24 students who underwent AI-based physics learning. The mean difference between the posttest and pretest scores is 19.17, with a standard deviation of 5.20 and a standard error mean of 1.06. The 95% confidence interval for the mean difference ranges from 16.93 to 21.41, indicating that we can be 95% confident that the true mean difference lies within this interval. The t-value obtained from the test is 18.06, with 23 degrees of freedom. The significance value (p-value) is 0.000, which is less than the conventional alpha level of 0.05. This indicates that the difference in scores before and after the intervention is statistically significant.

The study is large mean increase of 19.17 points and the highly significant p-value ($p < 0.001$) demonstrate that students' understanding of physics concepts improved substantially after the AI-based learning was implemented. This result supports the effectiveness of integrating artificial intelligence into physics education to enhance learning outcomes. The results of this study provide compelling evidence of the positive impact of Artificial Intelligence (AI)-based learning on students' understanding of physics concepts. This is demonstrated by the significant increase in posttest scores compared to pretest scores among the 24 students in the Physics Education program. The average pretest score was 62.08, which increased to an average posttest score of 81.25. This marked improvement, supported by the paired sample t-test results ($t = 17.82$, $p < 0.001$), indicates that the integration of AI tools into physics instruction can significantly enhance students' academic performance.

These findings are consistent with several previous studies that highlight the effectiveness of AI in improving educational performance. For example, research by Bakti et al. (2023) reported that the use of AI-driven adaptive learning platforms significantly enhanced students' conceptual understanding and engagement in STEM found that AI-powered educational tools improved student motivation and personalized learning pathways, leading to better academic achievement. In this study, students not only showed improved scores but also experienced more structured and responsive learning environments (Sukmawati et al., 2023).

Physics, as a subject, often poses significant challenges to students (Sukmawati et al., 2022). Traditional instructional methods may not fully address individual differences in student understanding, pace of learning, and conceptual grasp. AI-based learning systems offer a solution to this problem by delivering adaptive content, immediate feedback, and real-time assistance—features that were implemented in the AI tools used during this study. This aligns with the framework proposed by Luckin et al. (2016), who emphasized that AI in education should augment teachers' capabilities and personalize student experiences to support deeper learning.

The substantial increase in posttest performance further supports the claim that AI-enhanced instruction can serve as a cognitive scaffold, helping students connect abstract theoretical knowledge with concrete applications. Tools such as AI-based simulations, intelligent tutoring systems, and physics-focused chatbots likely contributed to this improvement by enabling students to visualize physical phenomena, receive tailored feedback, and engage in interactive problem-solving tasks. This mirrors findings from Alam (2023) who observed that AI-supported physics simulations improved students' comprehension of kinematic and dynamic concepts.

Moreover, the high correlation ($r = 0.75$, $p < 0.001$) between the pretest and posttest scores indicates a consistent pattern of improvement among the sample, suggesting that the AI intervention had a uniformly positive impact across the group of 24 students. This uniformity is crucial in teacher education programs, where the goal is not only academic mastery but also preparing future educators who can adapt to and adopt innovative teaching practices (Kozov et al., 2024).

From a pedagogical perspective, the results of this study reinforce the need to integrate AI technologies into teacher training curricula, especially in science education. By exposing future physics teachers to AI-based instructional tools, universities can better prepare them to use such technologies in their own classrooms, thereby closing the gap between educational theory and modern teaching practice (Vaishya et al., 2020). This is supported by Alsaleh (2020), who argue that AI literacy should be a core component of teacher education in the 21st century.

In summary, the results of this study provide strong evidence that AI-based learning significantly enhances student performance in physics education. These findings contribute to the growing body of literature that supports the pedagogical integration of AI in higher education and suggest that such innovations should be strategically incorporated into teacher training programs to foster both technological competence and improved learning outcomes.

The findings align with previous research highlighting the benefits of AI in education. AI provides personalized, adaptive learning experiences that cater to individual student needs and learning paces. Unlike traditional one-size-fits-all teaching methods, AI-driven platforms can diagnose student weaknesses, offer targeted practice, and provide instant feedback, which are crucial for mastering complex scientific concepts like those found in physics. This personalized approach likely contributed to the increased scores seen in this study. Moreover, AI applications often include interactive simulations and visualizations that make abstract physics concepts more concrete and accessible. For example, virtual laboratories and AI-powered problem-solving assistants allow students to experiment and learn in a risk-free, engaging environment, fostering deeper understanding and curiosity. The increased posttest scores suggest that such interactive features effectively supported student learning.

In addition to improving understanding, AI-based learning appears to enhance student engagement and motivation. The significant gain scores (mean N-Gain = 0.53, categorized as medium) suggest that students were actively involved in the learning process. Motivation is a critical factor in academic success, particularly in challenging subjects like physics. AI systems that provide immediate, personalized feedback and adaptive challenges can help maintain student interest and reduce frustration. This, in turn, may lead to higher persistence and better learning outcomes.

The successful application of AI in this study supports calls for greater integration of AI technologies into higher education curricula, especially in STEM fields. Physics, with its complex theoretical and mathematical underpinnings, benefits from AI's ability to present material in varied formats suited to different learning styles. Educators should consider incorporating AI tools that facilitate both conceptual understanding and problem-solving skills.

However, this integration requires thoughtful implementation. Educators need training to effectively use AI tools and interpret data outputs to guide instruction (Haleem et al., 2022). Furthermore, AI should complement, not replace, traditional teaching. The role of the instructor as a mentor, motivator, and facilitator remains vital. While the results are promising, the study has limitations. The sample size of 24 students is relatively small and drawn using purposive sampling, which may limit the generalizability of the findings. Future research with larger, randomized samples would help validate and extend these results. Additionally, the study employed a one group pretest-posttest design, which, while useful for initial investigations, lacks a control group. This limits the ability to conclusively attribute improvements solely to the AI-based intervention, as other variables such as maturation or testing effects could contribute. Future studies could adopt quasi-experimental designs with control groups to strengthen causal inferences.

The study also focused primarily on quantitative test scores. While these are important, qualitative data such as student attitudes, experiences, and perceptions of AI-based learning could provide richer insights into the mechanisms driving the observed improvements. Building on these findings, future research could explore long-term impacts of AI-based learning on students' academic trajectories and attitudes toward physics. Investigating how different AI tools or platforms compare in effectiveness would also be valuable. Moreover, exploring integration strategies for AI in blended learning environments combining traditional face-to-face instruction with AI-based components may offer practical insights for educators. Despite the promising outcomes, it is also important to consider some challenges and limitations. The study involved a relatively small sample size (n = 24), and the design followed a one-group pretest-posttest model without a control group. While the statistical findings are robust, further research with larger and more diverse samples, as well as control groups, is necessary to validate and generalize these results. Additionally, future studies could investigate long-term retention of concepts, student perceptions of AI tools, and the role of teacher facilitation in AI-supported environments.

In the context of Physics Education, incorporating AI tools that support collaborative learning could be another avenue. Many AI systems currently focus on individual learning, but physics often benefits from peer discussion and teamwork. Developing AI applications that foster group problem-solving and knowledge sharing could further enhance learning outcomes.

## Conclusion

The analysis of the pretest and posttest scores from 24 students who participated in AI-based physics learning shows a significant improvement in their academic performance. The descriptive statistics indicate that the mean score increased from 62.08 in the pretest to 81.25 in the posttest, with a reduction in score variability, suggesting more consistent learning outcomes. The strong positive correlation ($r = 0.75$, $p < 0.001$) between pretest and posttest scores indicates a consistent relationship in students' performance before and after the intervention. Furthermore, the paired samples t-test revealed a statistically significant increase in scores (mean difference = 19.17, $t(23) = 18.06$, $p < 0.001$), confirming the effectiveness of the AI-based learning method in enhancing students' understanding of physics. Overall, these results support the conclusion that integrating artificial intelligence into physics education positively impacts student learning outcomes by improving knowledge acquisition and creating a more consistent and supportive learning environment. This study contributes to the growing body of evidence supporting the use of Artificial Intelligence in education, particularly in STEM disciplines like physics. The significant improvements in student learning outcomes after AI-based instruction underscore the potential of these technologies to transform traditional teaching and learning processes. However, careful design, implementation, and further research are essential to maximize their benefits and address existing limitations. Educators, institutions, and policymakers should consider investing in AI-driven educational tools and training programs to prepare for an increasingly digital learning landscape. Ultimately, the integration of AI in physics education can play a crucial role in preparing students for the demands of the 21st century by fostering deeper understanding, engagement, and skills development.

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The authors declare no conflict of interest.

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