



THE IMPACT OF AI-BASED BLENDED LEARNING ON LEARNING ACHIEVEMENT AMONG SECOND-YEAR PHYSICS STUDENTS AT THE COLLEGE OF EDUCATION

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Abstract:

This study aimed to investigate the impact of AI-based blended learning on the learning achievement of second-year physics students at the College of Education. The researchers employed a quasi-experimental design, with the study population comprising second-year students in the physics department. A purposive sample of 40 students was selected and divided into two equivalent groups: an experimental group and a control group, each consisting of 20 students. The researchers used achievement tests as data-collection tools, and appropriate statistical methods were applied to analyze the data using the Statistical Package for the Social Sciences (SPSS). The study concluded with several findings, the most significant of which included the presence of statistically significant differences at the 0.05 significance level in the academic achievement of second-year students in mathematics, favouring the experimental group that was taught using an AI-based blended learning strategy. Based on these results, the researchers recommended establishing a blended-learning infrastructure by preparing human resources and equipping computer laboratories appropriately to implement the blended-learning strategy effectively. They also suggested adopting blended learning strategies in teaching science in schools and universities, and organizing workshops and training sessions for faculty members on AI-based blended learning.

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INTRODUCTION

This era has witnessed significant advancements across various fields, resulting in discoveries that have revolutionized, especially in information and communication technology. One of its notable achievements is the emergence of e-learning, which is considered one of the most important modern methods (Bahari, 2022; Chow et al., 2023; Narayanan et al., 2021; Samonte et al., 2023). It helps address information overload, alleviates overcrowding in lecture halls, and expands educational access, thereby increasing the number of learners and combating illiteracy. E-learning also facilitates live online interactions and provides up-to-date information that aligns with learners' needs, allowing individuals to learn at their own pace (Mehrfar et al., 2024; van et al., 2022; Yu et al., 2022).

The reality faced by researchers, coupled with the poor outcomes of the educational process, indicates a pressing need to activate this mode (blended learning). Many studies have highlighted this need, including the study by van et al. (2023), Bouranta et al. (2024), and Bouranta et al. (2024), which confirmed that reports written by students who engaged in blended learning were of higher quality, submitted more

promptly, and of better quality than the same reports prepared by their peers who had only experienced e-learning.

Despite the advantages of blended learning, such as flexibility to accommodate diverse learning needs and styles, cost efficiency compared to fully online models, and enhanced interaction among learners (Benjelloun, 2023; Ilieva et al., 2023; Morze, Varchenko-Trotsenko, Terletska, & Smyrnova-Trybulska, 2021). Its implementation remains challenging in many educational contexts. Several obstacles stem from weaknesses in the structural components of blended learning systems. These challenges include inadequate technical infrastructure, such as limited access to computers and online assessment platforms, as well as insufficient internet connectivity (D'andria, Fiore, & Nesticò, 2021; Elkordy & Iovinelli, 2021; Kerdnaimongkol, 2025). In addition, human-related factors pose significant barriers, including teachers' limited proficiency with modern educational technologies, resistance to shifting away from traditional teaching methods, the digital divide between instructors and students, and difficulties related to cultural adaptation.

Despite these challenges, various types of blended learning models have emerged in recent years, including the rotation model, flexible model, selective model, and enhanced virtual model. Among these, the rotation model is the most common, consisting of four sub-models, one of which is the flipped classroom model (Al-Haddad, Chick, & Safi, 2024; Cai, Li, Hu, Li, & Khoshnood, 2022; İbili et al., 2024). Although the flipped classroom model is an evolution of blended learning, its approach and concept make it an independent style. Artificial intelligence (AI) can track each learner's activities, providing guidance that highlights their strengths and weaknesses and offers appropriate support. AI can provide faculty members with data on student performance and their responses at each step, enabling them to determine how to interact with the learner to improve performance and provide feedback (Karthik et al., 2023; Tantiphlachiva et al., 2023). Feedback can be immediate, or after completing all educational tasks, and remedial educational activities can also be offered.

Mathematics plays a crucial role in physics education, as it forms the foundation for conceptual understanding and problem-solving in scientific disciplines. However, despite rapid technological advancements in education, instructional practices in mathematics often remain dominated by traditional lecture-based approaches. This reliance on conventional methods may limit students' engagement, conceptual depth, and long-term retention of knowledge. Previous studies have emphasized the potential of artificial intelligence applications to enhance learning outcomes. However, empirical research examining the integration of AI within blended learning environments, particularly in mathematics courses for physics students, remains limited. This gap highlights the need to systematically investigate whether AI-based blended learning can significantly improve academic achievement compared to traditional instructional strategies. Accordingly, this study seeks to address the following research question: What is the impact of AI-based blended learning on academic achievement and knowledge retention in mathematics among second-year physics students?

This study argues that integrating artificial intelligence into a blended learning framework can meaningfully enhance students' academic achievement and retention by providing adaptive feedback, personalized learning pathways, and data-driven instructional support. The provisional answer to the research problem is that AI-based blended learning is more effective than traditional teaching methods in fostering deeper

cognitive engagement and sustained learning outcomes. The originality of this study lies in its empirical examination of AI integration within a blended learning model in a higher education STEM context where technological infrastructure and digital readiness present unique challenges. By combining quasi-experimental analysis with retention measurement, this research contributes both methodologically and theoretically to the field of AI-assisted education. It extends existing scholarship beyond general e-learning discussions and offers evidence-based insights for implementing AI-driven instructional strategies in comparable educational environments.

RESEARCH METHODS

Research Questions

This study employs a quasi-experimental design to examine the impact of AI-based blended learning on the academic achievement and knowledge retention of second-year physics students at the College of Education, University of Khartoum (Sanz-Mas et al., 2024). The research was designed to compare two groups of students: an experimental group that received AI-supported blended learning and a control group that received traditional instructional methods. The blended learning model used in this study combined in-person classroom instruction with AI-enabled online learning, providing students with personalized learning experiences, automated feedback, and real-time progress tracking. To ensure validity, both groups were given a pre-test before the intervention and a post-test after completing the instructional period. The difference in scores between these tests helped measure the impact of AI-based blended learning on students' academic performance. Additionally, retention tests were administered after a designated period to evaluate how well students maintained their knowledge over time.

The sample selection process followed a purposive sampling technique, targeting second-year students enrolled in a mathematics course within the physics department (Ratnawati et al., 2024). The rationale for selecting this particular group was the need for strong mathematical foundations in physics education and the observed challenges students face in mastering complex mathematical concepts. The sample consisted of two groups of equal size, ensuring that both had similar academic backgrounds and baseline knowledge levels before the intervention. The experimental group used an AI-enhanced blended learning platform that included adaptive learning paths, automated assessments, and AI-generated instructional feedback. This group also had access to supplementary digital resources, including interactive simulations and video tutorials tailored to their learning progress. In contrast, the control group received instruction exclusively through traditional lecture-based teaching, supplemented with printed materials and standard classroom discussions. This division enabled a direct comparison of the effectiveness of AI-based blended learning and conventional teaching methods.

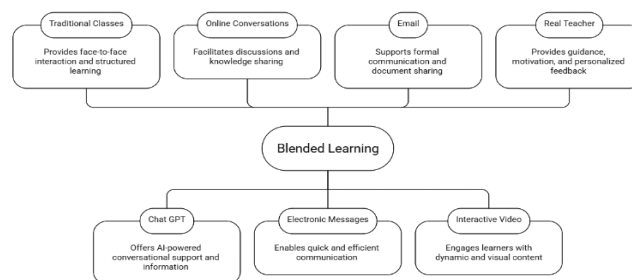


Figure 1. Enhancing Education with Blended Learning

Figure 1 shows that multiple assessment instruments were used to ensure a comprehensive evaluation of student learning outcomes. The achievement tests were carefully designed to assess students' conceptual understanding, problem-solving abilities, and overall grasp of mathematical principles before and after the intervention. These tests were validated through expert reviews to confirm their alignment with course objectives and learning outcomes. Additionally, a retention test was administered after a predetermined period to measure students' ability to recall and apply previously learned concepts. In addition to quantitative assessments, qualitative data were collected through structured student feedback surveys and instructor observations. These tools helped capture students' levels of engagement, perceived challenges, and overall experiences with the AI-based blended learning model. Instructor observations focused on students' interaction with AI tools, participation in collaborative learning activities, and their ability to navigate through digital learning materials independently.

For data analysis, both descriptive and inferential statistical methods were employed to interpret the results. T-tests and ANOVA were conducted to compare the pre-test and post-test scores between the control and experimental groups, helping determine the statistical significance of any observed differences. Additionally, retention test scores were analyzed to evaluate the long-term effectiveness of AI-based blended learning in maintaining knowledge. To supplement the quantitative findings, qualitative data from student surveys and instructor observations were analyzed using thematic coding, identifying recurring themes related to students' learning experiences, technological engagement, and perceived benefits and limitations of AI integration in education. These insights provided a deeper understanding of the broader implications of AI-assisted blended learning in higher education. They helped formulate recommendations for future applications of this model in similar learning environments.

Objectives of the Study

This study aims to identify the impact of AI-based blended learning on academic achievement in mathematics among second-year physics students compared with traditional teaching methods, and to examine its effect on students' knowledge retention compared with that of students who learn through conventional instructional approaches.

Significance of the Study

This study may enrich the theoretical literature on blended learning and address the needs of the educational field in the Arab world by adopting a new educational model across various educational stages and disciplines. This approach aligns with the preferences of digital generation students, facilitating the transformation of the educational process into a learning experience. Furthermore, the findings of this study can assist educational stakeholders in identifying the most suitable ways to implement blended learning in general education programs. It can also provide recommendations to enhance the use of blended learning methods in teaching. This study highlights the evolving role of the teacher, transitioning from a mere transmitter of information to a designer of the educational environment and planner of instructional methods within the classroom.

Concept of Blended Learning

Views on the definition of blended learning vary significantly, leading researchers to offer different interpretations based on their preferred integration methods. To clarify the concept, it is beneficial to present several definitions. Shahba et al. (2022) indicate that blended learning represents the latest development in education and teaching, essentially combining e-learning with other teaching methods. Rayyan et al. (2024) define it as an approach that integrates learning and teaching by merging traditional face-to-face strategies with virtual educational strategies.

Elements of Blended Learning

Blended learning encompasses various elements that can be combined to create this type of education. Any number of these elements can be integrated, including (Khan, Ramsey, & Khan, 2023): **Face-to-face interaction:** Traditional classroom instruction where teachers and students interact directly. **Online Learning:** Digital courses or materials that students engage with independently or in a structured online environment. **Collaborative Activities:** Group work and projects that may occur both online and in person. **Self-Paced Learning:** Opportunities for students to learn at their own pace, utilizing online resources. **Multimedia Resources:** The use of videos, podcasts, and other digital content to enhance learning. **Feedback Mechanisms:** Systems that provide students with timely, constructive feedback on their performance. By blending these elements, educational institutions can create a more flexible and effective learning environment that meets the diverse needs of students.

Features of Blended Learning

Blended learning is characterized by several key features that enhance the effectiveness and efficiency of the educational process. First, it reduces costs by lowering learning expenses compared to fully online models, as it optimizes the use of both digital and in-person resources. Second, it maintains face-to-face interaction, enabling learners to benefit from direct engagement with teachers and peers, which supports clearer communication and immediate feedback. Third, it strengthens human aspects of learning by promoting social relationships and meaningful collaboration among students and between students and instructors. Additionally, blended learning enriches knowledge acquisition by integrating diverse learning resources, thereby improving both the quality of instruction and educational outcomes. It also enhances teacher efficiency through flexible instructional design and better classroom management. Finally, blended learning fosters cultural communication by connecting learners from different backgrounds and encouraging mutual exchange of scientific and academic advancements.

Alternatives for Implementing Blended Learning

Some educational literature has highlighted several approaches to implementing the blended learning model. Below is a brief description of these alternatives (El et al., 2021):

Alternative One: In this model, a specific lesson is taught using traditional classroom methods, while another lesson is taught using online learning tools. Students are then assessed using traditional or electronic methods. This alternative assumes that online learning may not be suitable for certain subjects, making traditional classroom methods preferable for these topics.

Alternative Two: In this model, both classroom teaching and online learning share the responsibility for teaching a single lesson. It starts with classroom instruction, followed by online learning. Finally, students are assessed using traditional or electronic methods, as illustrated in the figure.



Figure 2. The second alternative for implementing blended learning.

Alternative Three: This alternative is similar to Alternative Two, except that it begins with online learning, followed by classroom instruction. The final assessment is conducted using either traditional or electronic methods, as illustrated in the figure.

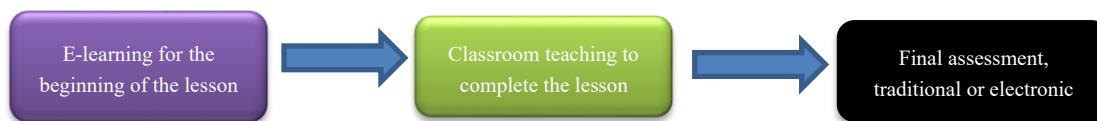


Figure 3. The third alternative for implementing blended learning.

Alternative Four. This alternative resembles both Alternatives Two and Three, but the interaction between classroom teaching and online learning occurs multiple times within a single lesson rather than just once. The final assessment is conducted using either traditional or electronic methods, as illustrated in the figure.

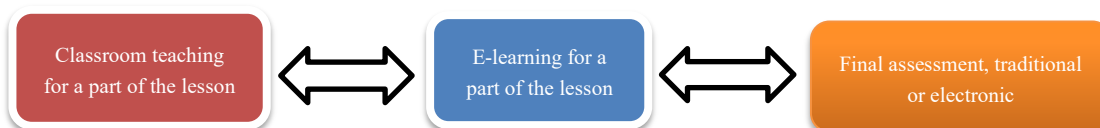


Figure 4. The fourth alternative for implementing blended learning. Obstacles Facing the Implementation of Blended Learning and How to Overcome Them

Despite the significant progress in the use of blended learning in education and training in the U.S. and Western countries, its implementation in developing countries is still in a trial phase, if it has even started in many of them. Undoubtedly, numerous obstacles and challenges face the application of blended learning in these contexts. These obstacles include funding, infrastructure, technical issues, and social factors.

According to El et al., several major obstacles hinder the effective implementation of blended learning. These include technical challenges, particularly the need to master modern technologies and keep pace with the rapid development of computer systems; weak communication infrastructure in some countries, which limits reliable internet access; and language barriers, as many technological tools and resources are predominantly available in English. Economic factors also pose difficulties, especially in funding educational projects at both the individual and national levels. Additionally, resistance to change among some teachers and educational professionals can impede the adoption of modern technologies. Finally, blended learning requires strong student motivation, enthusiasm, and sustained commitment, making the cultivation of learner motivation an essential component for its success.

RESULTS AND DISCUSSION

Results

This section presents the study's findings on the impact of AI-based blended learning on students' academic achievement and knowledge retention. The results are organized to systematically address the research questions, beginning with achievement outcomes and then proceeding to retention analysis. Statistical evidence and comparative interpretations are provided to clarify the intervention's effectiveness.

Concept of Artificial Intelligence

Artificial intelligence (AI) is a technological advancement designed not only to enhance technical efficiency but also to simulate human cognitive processes, including perception, reasoning, learning, and decision-making. The concept refers to the development of intelligent systems, particularly computer-based programs, that are capable of processing information, adapting to new data, and performing tasks in ways comparable to human thinking. AI represents a significant shift from conventional information technology, emphasizing autonomous analysis and problem-solving rather than merely accelerating computational processes.

Artificial intelligence can be categorized into three primary levels based on its capabilities. Narrow AI represents the most basic level, focusing on performing specific, predefined tasks within limited contexts. Strong AI refers to more advanced systems capable of forming internal knowledge structures and making context-based decisions using available data, as seen in applications such as autonomous vehicles and interactive digital assistants. The most advanced level, Superintelligent AI, remains largely theoretical and experimental, encompassing systems that can interpret emotional states, simulate human-like consciousness, and anticipate others' reactions and behaviors.

Goals of Artificial Intelligence

The results indicate that integrating artificial intelligence into a blended learning environment positively affects students' academic achievement and knowledge retention. The implementation of AI-supported strategies, including structured digital presentations, augmented learning displays, organized distribution of academic resources across departments, and integrated research support mechanisms, enhanced students' engagement and facilitated more efficient access to learning materials. These structured steps enabled students to complete academic tasks more systematically and encouraged the development of innovative ideas beyond regular classroom hours. The findings suggest that AI-based blended learning moves beyond traditional information technology use by actively supporting cognitive processes such as problem-solving and decision-making rather than merely increasing instructional speed.

Statistical analysis revealed significant differences between pre-test and post-test scores, favoring post-test performance, indicating measurable improvement after the intervention. Students exposed to AI-based blended learning demonstrated higher levels of academic achievement and improved retention compared to their baseline results. The calculated means and standard deviations, along with t-test results for related groups, confirmed that the observed differences were statistically significant. These findings demonstrate that AI-enhanced blended learning has a meaningful positive effect on both immediate academic performance and sustained knowledge retention among second-year physics students.

Presentation, Analysis, and Discussion of Results

To answer the first question, which is: **What is the effect of blended learning based on artificial intelligence on academic achievement in mathematics among second-level Physics students compared to the traditional method?** To address this question, the means and standard deviations of the study groups' performance on the pre-test and post-test in mathematics were calculated. Table (1) illustrates this:

Table 1. Means and standard deviations of the study groups in the pre-test and post-test in mathematics

Comparison Groups	Number	Pre-Test Mean	Pre-Test Standard Deviation	Post-Test Mean	Post-Test Standard Deviation
Experimental	20	23.8718	4.6955	26.8718	5.6955
Control	20	23.5385	4.0012	23.5385	5.0012
Total	40				

It can be observed from Table 1 that the mean score for the experimental group, which studied using the blended learning strategy, was higher at (26.8718), while the mean score for the control group, which studied using the traditional method, was (23.5385). To determine whether the differences between the means of the study groups were statistically significant at the significance level ($0.05 \geq \alpha$), a mixed ANOVA was applied, as illustrated in the following table:

Table 2. Results of the mixed ANOVA for the differences between the mean scores of the study groups in the post-test of mathematics

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	Calculated F Value	Significance Level
Pre-Test Application	84.56	1	84.56	10.213	0.001
Blended Learning	125.265	2	112.265	12.265	0.000
Error	756.568	120	5.256		
Total Adjusted	1126.546	127			

Table 2 shows that the F value for the blended learning strategy was 12.265, with a significance level of 0.000. This value is statistically significant at the 0.05 level (α), indicating that there are significant differences in the mean performance of the study groups on the academic achievement test in mathematics. This confirms that there are significant differences in the academic achievement of second-level students in mathematics attributed to the teaching strategies (blended learning vs. traditional education). The adjusted means were extracted, and the Scheffé test was applied for post-hoc comparisons to identify which group showed the difference. The results are shown in Tables (3) and (4):

Table 3. Adjusted means and standard errors of the study groups' performance in the post-test of mathematics

Group	Number	Adjusted Mean	Standard Error
Experimental	20	26.5	0.36
Control	20	24.6	0.35

Table 3 shows that the adjusted mean for the experimental group, which used the blended learning strategy, was 26.5, while the adjusted mean for the control group, which used the traditional method, was 24.6. The results of the Scheffé test for post-comparisons between the adjusted means are as follows:

Table 4. Results of the Scheffé test for the differences in performance among the study groups in the adjusted means on the academic achievement test in mathematics:

Group	Adjusted Mean	Experimental	Control
Experimental	26.5	-	2.20*
Control	24.6	-	-

*Significant at the level of $(0.05 \geq \alpha)$.

Table 4 shows that the difference favored the experimental group, which learned using a blended learning strategy based on artificial intelligence, compared with the control group, which learned using the traditional method. This indicates that learning through a blended, AI-based strategy effectively enhanced academic achievement in mathematics. The researchers attribute this result to the fact that blended learning based on artificial intelligence involves multiple dimensions across its activities, thereby enhancing students' self-confidence and providing immediate feedback. This led to increased academic achievement among the sample members. On another note, this result reflects the effectiveness of blended learning based on artificial intelligence in improving student performance, as it provided a sequence of content along with associated activities and multimedia, which motivated students to learn.

To answer the second question:

What is the effect of blended learning based on artificial intelligence on the retention of learning among second-level students compared to the traditional method? To address this question, the means and standard deviations of the study groups' performance on the retention test in mathematics, along with their pre-test scores, were calculated. Table 5 illustrates this:

Table 5. Means and standard deviations of the study groups' performance in the post-test and retention test in mathematics

Comparison Groups	Number	Pre-Test Mean	Pre-Test Standard Deviation	Post-Test Mean	Post-Test Standard Deviation
Experimental	20	26.8718	5.6955	24.2565	5.3595
Control	20	23.5385	5.0012	20.2658	5.1269
Total	40				

It can be observed from Table 5 that the mean score for the first experimental group, which studied using the blended learning strategy based on artificial intelligence, was higher at (24.2565), while the mean score for the control group, which studied through the traditional method, was (20.2658). To determine whether the differences between the means of the study groups were statistically significant at the significance level $(0.05 \geq \alpha)$, a mixed ANOVA was applied, as illustrated in the following table:

Table 6. Results of the mixed ANOVA for the differences between the mean scores of the study groups in the retention test in mathematics

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	Calculated F Value	Significance Level
Pre-Test Application	317.54	1	317.54	152.658	0.000
Blended Learning	122.652	2	39.365	16.365	0.000
Error	344.568	120	2.365		
Total Adjusted	1255.352	127			

From Table 6, it is clear that the F value for the blended learning strategy was (16.365) with a significance level of (0.000). This value is statistically significant at the 0.05 level (α), indicating that there are significant differences in the mean performance of the study groups on the retention test in mathematics. This confirms that there are significant differences ($0.05 \geq \alpha$) in the retention of learning among second-level Physics students in mathematics attributed to the teaching strategies (blended learning vs. traditional education). The adjusted retention means were extracted, and the Scheffé test was applied for post-hoc comparisons to identify which group showed the difference. The results are shown in Tables 7 and 8:

Table 7. Adjusted means and standard errors of the study groups' performance in the retention test in mathematics

Group	Number	Adjusted Mean	Standard Error
Experimental	20	24.7	0.27
Control	20	22.6	0.26

Table 7 shows that the adjusted mean for the experimental group, which used a blended learning strategy based on artificial intelligence, was 24.7, while the adjusted mean for the control group, which used the traditional method, was 22.6. The results of the Scheffé test for post hoc comparisons are as follows:

Table 8. Results of the Scheffé test for the differences in performance among the study groups in the adjusted means on the retention test in mathematics

Group	Adjusted Mean	Experimental	Control
Experimental	24.7	-	2.06*
Control	22.6	-	-

***Significant at the level of ($0.05 \geq \alpha$).**

Table 8 and the Scheffé test indicate that the difference favored the experimental group that learned using the blended learning strategy based on artificial intelligence, compared with the control group that learned through the traditional method. This means that learning using a blended, AI-based strategy was effective at retaining knowledge in mathematics. This can be explained by the fact that blended learning based on artificial intelligence supports collaborative learning and a spirit of cooperation among peers. Students engage in dialogue with their peers before class through various social media networks (flipped learning) or during research tasks online in the classroom (blended learning), among other activities. This creates a learning environment that may help retain the information discussed, making it easier for students to remember than in traditional classrooms, where the teacher plays a larger role.

Discussion

The findings of this study demonstrate that AI-based blended learning significantly improves the academic achievement of second-year physics students compared to the traditional method. The higher post-test mean score of the experimental group (26.8718) compared to the control group (23.5385), along with a statistically significant F value (12.265, $p = 0.000$), confirms the effectiveness of the intervention. These results are consistent with prior literature on blended learning, which highlights the benefits of integrating face-to-face and digital instruction to enhance student engagement and flexibility. Moreover, the findings align with studies on artificial intelligence in education

that emphasize adaptive feedback, personalized learning pathways, and real-time performance monitoring as key factors in improving learning outcomes (Marisa, Gunawan, & Susilawati, 2024; Winkel et al., 2023). Unlike traditional teacher-centered approaches, AI-supported blended learning shifts the focus to a more student-centered, cognitively engaging environment.

From a theoretical perspective, these results support constructivist learning theory, which posits that learners actively construct knowledge through meaningful interaction and problem-solving. AI-based systems in this study functioned not merely as content-delivery tools but also as cognitive facilitators that guided students in analysis, reasoning, and decision-making (Bernstein et al., 2022; Martins et al., 2021; Utamimah et al., 2025). The structured digital presentations, integrated research support, and organized distribution of learning materials appear to have strengthened higher-order thinking skills (Farrokhnia, Banihashem, Noroozi, & Wals, 2024; Lai, 2024). This confirms theoretical arguments that intelligent technologies can enhance deep learning processes rather than simply accelerating information transmission.

Regarding knowledge retention, the results also revealed a statistically significant difference in favor of the experimental group ($F = 16.365$, $p = 0.000$). The adjusted mean retention score of the experimental group (24.7) exceeded that of the control group (22.6), indicating that AI-based blended learning had a sustained impact beyond immediate post-instruction performance. These findings are consistent with cognitive elaboration theory and social learning theory, which emphasize the importance of interaction, repetition, and collaborative engagement in strengthening long-term memory (Iscan et al., 2023; Qi, 2021; Salas et al., 2023). The inclusion of flipped learning activities, peer discussions, and AI-supported online research tasks likely reinforced memory consolidation by encouraging repeated exposure and active processing of information.

Although the statistical differences were significant, the magnitude of improvement suggests that the effectiveness of AI-based blended learning depends on careful instructional design and proper technological integration. Existing literature cautions that technology alone does not guarantee improved outcomes; rather, its pedagogical alignment determines its impact. In this study, the structured sequencing of content, multimedia integration, and immediate feedback mechanisms appear to have contributed substantially to student confidence and self-regulated learning. Therefore, the success of AI integration should be understood as a synergy between intelligent systems and sound pedagogical strategies.

Theoretically, this study contributes empirical evidence to the growing body of research on AI-enhanced learning in higher education by demonstrating its dual impact on academic achievement and knowledge retention. It reinforces the conceptualization of AI as a cognitive support system within blended learning environments. Practically, the findings suggest that higher education institutions should strategically adopt AI-based blended models in curriculum planning, faculty development, and digital infrastructure investment. By doing so, universities can foster more adaptive, interactive, and sustainable learning environments that enhance both immediate academic performance and long-term knowledge retention in physics education and beyond.

CONCLUSION

This study concludes that AI-based blended learning has a statistically significant and meaningful impact on both academic achievement and knowledge retention among second-year physics students. The experimental group demonstrated higher post-test mean scores (26.8718) than the control group (23.5385), as evidenced by a significant F value (12.265, $p = 0.000$). Similarly, retention results favored the experimental group, with an adjusted mean of 24.7 compared to 22.6 in the control group ($F = 16.365$, $p = 0.000$). These findings highlight an important lesson: when artificial intelligence is pedagogically integrated into blended learning environments, it can enhance cognitive engagement, provide adaptive feedback, and strengthen long-term memory consolidation. The study's strength lies in its empirical validation of AI as a cognitive support tool rather than merely a technological supplement. By combining quantitative statistical analysis with structured instructional intervention, this research contributes scientifically grounded evidence to the evolving discourse on AI-enhanced higher education learning models.

Despite its contributions, this study has several limitations that should be acknowledged. The sample size was relatively small (40 students) and drawn from a single academic context, which may limit the generalizability of the findings to broader educational settings. Additionally, the quasi-experimental design, while practical, may not fully control for all external variables influencing student performance. The intervention period was also limited, restricting the ability to examine long-term longitudinal effects of AI-based blended learning. Future research should involve larger and more diverse samples across multiple institutions and disciplines to enhance external validity. Longitudinal studies are recommended to assess sustained academic development over extended periods. Further investigation into different AI tools, levels of personalization, and their interaction with various pedagogical models would deepen understanding of how intelligent systems can be optimally integrated into science education and other STEM fields.

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