

When Artificial Intelligence Meets Blended Learning: A Quasi-Experimental Study of Physics Achievement at the University of Khartoum, Sudan

Bannaga Taha Elzubair Hessen, Olash Abdalrheem Hewary, Nedal Guma Fileen

^{1,2,3}University of Khartoum, Sudan

e-mail: banagataha@gmail.com, olashabdu2012@gmail.com, nwnaflyn@gmail.com

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ABSTRACT. Artificial intelligence (AI) has increasingly been integrated into blended learning environments to enhance instructional effectiveness in higher education. However, empirical evidence regarding its impact on student learning outcomes in science education remains limited in developing contexts. This study examines the effect of AI-based blended learning on the academic achievement of second-year physics students at the College of Education, University of Khartoum, Sudan. A quasi-experimental design was employed with 40 students assigned to an experimental group ($n = 20$) and a control group ($n = 20$). Data were collected via an achievement test and analyzed using SPSS. The findings reveal a statistically significant improvement in physics achievement for students exposed to the AI-based blended learning approach compared with those receiving conventional instruction ($p < 0.05$). These results indicate that integrating AI with blended learning can enhance learning effectiveness in science education. The study highlights the importance of strengthening institutional infrastructure and professional development to support the implementation of AI-supported blended learning in higher education.

Keywords: *Academic achievement; artificial intelligence in education; blended learning; physics education.*

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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 (Werner & Iwańczak, 2015; Eldow et al., 2020; El-Bably, 2022). One of its notable achievements is the emergence of e-learning, which is considered one of the most important modern methods (Tairab et al., 2016; Eldow et al., 2017; Eldow et al., 2018). It helps address information overload, alleviates overcrowding in lecture halls, and expands educational access, thereby increasing the number of learners and combating illiteracy (Uche et al., 2014; Stubbé et al., 2016). E-learning also facilitates live online interactions and provides up-to-date information aligned with learners' needs, allowing individuals to learn at their own pace (Er, 2009; Amity, 2020).

The empirical reality faced by researchers, coupled with suboptimal educational outcomes, demonstrates the urgent need to implement a blended learning approach as a strategic alternative to improve learning quality. Several studies have provided strong evidence of this approach's effectiveness. Kiviniemi (2014) confirmed that blended learning significantly improves student

academic performance compared to both fully online and conventional face-to-face learning models. This finding is supported by Niu et al. (2023), who found that students in a blended learning environment report higher levels of satisfaction, engagement, and self-confidence during the learning process. Thus, integrating online and face-to-face learning not only improves learning outcomes but also fosters a more meaningful and participatory learning experience.

Although blended learning offers several advantages, such as flexibility in accommodating individual needs and learning styles across levels and age groups (Owston, 2018; Albatti, 2023), cost-efficiency compared to fully online learning (Uukkivi et al., 2022; Efthymiou, 2024), and increased interaction between students (Kelly et al., 2021), its implementation still faces significant challenges. Studies indicate that many teachers struggle to utilize technology as a learning medium (Rasheed et al., 2020; Shah et al., 2024), with resistance to adopting new learning methods due to increased workloads and low professional confidence (Rasheed et al., 2020; Ali, 2025). Furthermore, limited training and inadequate institutional support contribute to structural barriers to the implementation of blended learning (Rasheed et al., 2020). From the student perspective, technological access constraints, including unstable internet connections, limited devices, and low digital literacy, are also major inhibiting factors for the successful implementation of this approach (Rasheed, 2020; Gabriel & Nyahwema, 2025).

Despite various implementation challenges, the development of blended learning in recent years has led to a range of learning models that are adaptive to student needs. These models include the rotation model, which allows students to move in a structured manner between different learning modalities (Anagnostopoulou et al., 2025); the flexible model, which places online learning as a central component with teacher support available as needed (Haftador et al., 2023); the self-blended model, in which students independently supplement face-to-face learning with additional online courses (Wang & Bhagat, 2025); and the enriched virtual model, which combines online learning with periodic face-to-face sessions (Krismadinata et al., 2020). Among these approaches, the rotation model is the most widely implemented and encompasses four submodels, one of which is the flipped classroom. Although the flipped classroom emerged from the evolution of blended learning, its approach and conceptual foundations make it a learning style with distinct pedagogical characteristics (Critz & Knight, 2013).

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. Feedback can be immediate, or after completing all educational tasks, and remedial educational activities can also be offered (Murphy, 2019). Therefore, this paper aims to examine the impact of AI-based blended learning on academic achievement and knowledge retention among second-year physics students at the University of Khartoum.

Mathematics is a fundamental subject that requires modern teaching strategies to keep pace with technological advancements, equipping students with essential concepts, attitudes, and skills. The researchers observed a lack of diversity in teaching strategies, as many teachers still rely on traditional methods. Through a review of previous studies, the researchers aimed to investigate the impact of both strategies, given the scarcity of studies on this topic. Moreover, many studies have recommended expanding the use of artificial intelligence applications in education to achieve better learning outcomes, as in Ocaña-Fernández et al. (2019). Therefore, the problem of this study is encapsulated in the following main question: What is the impact of AI-based blended learning on academic achievement in mathematics among second-year physics students at the College of Education, University of Khartoum? What is the impact of AI-based blended learning on academic achievement in mathematics among second-year physics students compared to traditional methods? What is the impact of AI-based blended learning on the retention of knowledge among second-year students compared to traditional methods?

This study aims to identify: (1) the impact of AI-based blended learning on academic achievement in mathematics among second-year physics students compared to traditional methods. (2) The effect of AI-based blended learning on the retention of knowledge among second-year students compared to traditional methods. 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.

METHOD

The nature, objectives, hypotheses, and data requirements for this research necessitate a quasi-experimental design to examine the effect of the independent variable (blended learning based on artificial intelligence) on the dependent variables (academic achievement and retention of learning). The study population comprises second-year male and female students in the Physics Department at the College of Education, University of Khartoum. A purposive sampling method was used to select the research sample, comprising second-year male and female students in the Physics Department at the College of Education, University of Khartoum.

Table 1: Distribution of the study sample according to the group and gender variable.

The Group	Number	Males	Females
Experimental Group	20	7	13
Control Group	20	4	16
The Total	40	11	29

The study employed an achievement test as the research tool. The data were analyzed and processed using the Statistical Package for the Social Sciences (SPSS). The researchers extracted and interpreted the results using the following methods: means, standard deviations, and the t-test for related groups. A stable test yields similar or identical results when applied repeatedly under similar conditions. To calculate the stability coefficient of the pre, post- and delayed tests, the researchers By selecting a random sample to represent a survey sample of community members consisting of (20) male and female students, and after applying the test to the survey sample, it became clear from the test questions that the appropriate time for it was (120) minutes, and then the stability coefficient of the pre-test, post-test and postponed test was calculated using the split-half method. From this, it was found that the stability coefficients for the pre- and post-test were 0.98, and for the delayed test, 0.97, both of which are high and acceptable.

RESULT AND DISCUSSION

Result

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. The means and standard deviations of the study groups in the pre-test and post-test

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

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 2.

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

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. The adjusted means and standard errors of the study groups' performance in the post-test

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. The results of the Scheffé test for the differences in performance among the study groups in the adjusted means on the academic achievement test

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.

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: The means and standard deviations of the study groups' performance in the post-test and retention test

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

Table 5 shows that the mean score for the first experimental group, which used the blended learning strategy based on artificial intelligence, was 24.2565, while the mean score for the control group, which used 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 Table 6.

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

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. The adjusted means and standard errors of the study groups' performance in the retention test

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. Shows the results of the Scheffé test for the differences in performance among the study groups in the adjusted means on the retention test

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 has a statistically and educationally meaningful impact on both academic achievement and learning retention among second-year physics students at the College of Education, University of Khartoum. Students exposed to this instructional approach consistently outperformed those taught through traditional methods, indicating that integrating artificial intelligence into blended learning environments enhances learning effectiveness in higher education.

The results of this study can be explained through the constructivist learning theory, which emphasizes the importance of active student involvement, social interaction, and feedback as the primary mechanisms of knowledge construction (Jumaat et al., 2017; Robinson et al., 2017). In this context, an artificial intelligence (AI)-based blended learning environment functions as a pedagogical ecosystem that supports this constructive process by providing personalized learning paths, adaptive feedback, and continuous monitoring of student learning progress (Davlatova & Chernobay, 2025; Kurniawan et al., 2025). These findings align with the views of Lai et al. (2019), who assert that e-learning environments can accommodate differences in individual characteristics while encouraging independent learning. Thus, AI integration serves not only as a technological tool but also as a pedagogical mediator that dynamically responds to students' learning needs, thereby strengthening the knowledge construction process, deepening conceptual understanding, and ultimately improving academic performance sustainably.

The positive impact of artificial intelligence (AI)-based blended learning on learning retention can be understood through the perspective of information processing and cognitive reinforcement theory, which places meaningful repetition, feedback, and information organization as key factors in the formation of long-term memory (Ji et al., 2024; Zakaria et al., 2024; Kumaresan et al., 2025; Yang, 2025). Unlike conventional learning, which tends to rely on a single channel for information delivery, blended learning environments provide multimodal exposure to material through a combination of face-to-face learning, digital resources, and online collaborative activities, thereby enriching learners' cognitive processing processes (Chu, 2025; Xiong et al., 2025). Similarly, Murphy (2019) demonstrated that AI-based systems strengthen retention through timely feedback, adaptive correction mechanisms, and personalized learning support, thereby directly enhancing the encoding and consolidation of information. Thus, integrating blended learning and AI not only increases the frequency of interaction with the material but also optimizes cognitive processing, resulting in more stable and sustainable learning retention than a single learning approach.

The findings of this study are consistent with previous empirical studies that confirm the effectiveness of blended learning in improving the quality of learning outcomes. Kiviniemi (2014) found that students participating in blended learning achieved higher-quality academic outcomes than those studying through traditional approaches or fully online learning, demonstrating the superiority of the hybrid approach in optimizing the learning experience. Similarly, Ocaña-Fernández et al. (2019) confirmed that integrating intelligent systems into the learning environment significantly improves academic achievement while supporting the sustainability of learning

outcomes. Comparatively, these two findings complement each other, namely the effectiveness of blended learning design and the strengthening of adaptive functions through intelligent technology. Thus, this study demonstrates the position of AI-based blended learning as a pedagogical strategy that is not only academically effective but also adaptive to the needs of 21st-century learning.

However, several studies report that the implementation of blended learning does not always run optimally, especially in educational contexts with limited technological infrastructure and low pedagogical readiness and teacher digital competency (Benson & Anderson, 2010; Kung-Teck et al., 2019; Shah et al., 2024). More specifically, Mohammadi et al. (2025) identified several key barriers, including complex technical demands, a digital literacy gap, and resistance to shifting from conventional to technology-based learning approaches. Compared with these findings, the results of this study indicate a different situation, likely influenced by the presence of systematically designed instructional materials and the integration of structured, pedagogically oriented AI tools. Therefore, the success of AI-based blended learning is not solely determined by the availability of technology, but rather by the quality of lesson planning, implementation readiness, and alignment between pedagogical strategies and technological support, thereby minimizing implementation barriers while significantly increasing student engagement.

This study makes significant contributions to the growing literature in several key aspects. First, it presents empirical evidence from Arab and developing countries, filling a research gap regarding the implementation of artificial intelligence (AI)-based blended learning in higher education, which developed countries have dominated. Second, the findings not only support but also expand the theoretical perspective on blended and flipped learning models (Florence & Kolski, 2021) by demonstrating that AI integration can enhance learning effectiveness without requiring radical changes to conventional pedagogical practices. Third, this study makes a practical contribution by offering implementable insights into the feasibility and adaptability of AI-based blended learning in resource-constrained institutional environments. Therefore, AI integration in blended learning can serve as a contextual, scalable, and relevant pedagogical innovation for higher education systems across diverse social and economic contexts.

From a practical perspective, the findings of this study provide strategic implications for educators, academic leaders, and education policymakers. For educators, artificial intelligence (AI)-based blended learning provides an opportunity to diversify teaching strategies, facilitate more personalized learning, and enhance student engagement and participation in a more meaningful way. Meanwhile, for higher education administrators and policymakers, the results of this study emphasize the urgency of investing in adequate technological infrastructure, strengthening human resource capacity, and providing ongoing professional training to support institutional readiness. Therefore, the successful implementation of AI-based blended learning depends not only on technology adoption but also on alignment between policies, educator competency development, and ongoing systemic support within the higher education ecosystem.

However, this study has several limitations that should be considered when interpreting the findings. First, the relatively small sample size and focus on a single academic department potentially limit the generalizability of the results to broader educational contexts. Second, this study focused on academic achievement and learning retention, thus failing to include affective dimensions, such as student motivation, perceptions, and attitudes toward artificial intelligence (AI)-based learning. Therefore, future research is recommended to involve a larger and more diverse sample, integrate cognitive and affective variables more comprehensively, and explore the long-term impact of AI-based blended learning across various disciplines and educational levels. Developing a broader research agenda would certainly strengthen external validity and deepen understanding of the effectiveness and sustainability of AI-based learning implementation in diverse educational contexts.

CONCLUSION

This study demonstrates that AI-based blended learning significantly improves the academic achievement of physics students in higher education. The quasi-experimental results show that students exposed to AI-supported blended learning outperform those taught through conventional instructional approaches. These findings reinforce the growing evidence that integrating artificial intelligence into blended learning environments can enhance instructional effectiveness by promoting interactive learning and responsive feedback. The study contributes to the literature on artificial intelligence in education by providing empirical evidence from a developing higher education context, highlighting the potential of AI-enhanced pedagogical models to improve science learning outcomes. However, the successful implementation of this approach depends on institutional readiness, including adequate technological infrastructure and faculty capacity development. Future studies should examine larger samples and diverse institutional contexts to further validate these findings.

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