



Enhancing Physics Literacy through AI-Augmented Contextual Learning

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Accepted: February 26th 2026, Approved: March 2nd 2026, Published: March 30th 2026

Abstract— *This study investigates the effectiveness of AI-augmented contextual learning in enhancing physics literacy among secondary school students. Using a mixed-method quasi-experimental design, 120 students were assigned to experimental and control groups. The intervention integrated contextual learning with AI-based simulations, adaptive learning platforms, and intelligent feedback systems. Quantitative data were analyzed using SPSS through normality and homogeneity tests followed by an independent samples t-test, while qualitative data were examined thematically to explore students' learning experiences. The results revealed a significant improvement in physics literacy in the experimental group compared to the control group ($t = 4.87, p < 0.001$, Cohen's $d = 0.82$). Students exposed to AI-augmented contextual learning demonstrated higher conceptual understanding, improved problem-solving skills, and stronger learning motivation. Qualitative findings supported these results, indicating that AI tools enhanced engagement and facilitated deeper connections between physics concepts and real-life contexts. These findings suggest that integrating AI within contextual learning environments significantly strengthens physics literacy and supports the development of scientifically literate, future-ready learners. The study provides empirical evidence for innovative AI-based instructional design in secondary physics education.*

Keywords— Physics Literacy, Artificial Intelligence, Contextual Learning, Future-Ready.

How to Cite— Istiqomah, L. (2026). Enhancing Physics Literacy through AI-Augmented Contextual Learning. *International Journal of Contextual Science Education*, 4(1), 1-4. <https://doi.org/10.29303/ijcse.v4i1.1241>



1. Introduction

Scientific literacy is widely recognized as a fundamental competency for 21st-century learners, particularly in science disciplines such as physics that foster analytical reasoning and problem-solving skills [7]. Despite its importance, many secondary students continue to perceive physics as abstract and disconnected from real-life applications, resulting in limited development of physics literacy. Physics literacy encompasses not only conceptual understanding but also the ability to apply scientific principles, interpret phenomena, and reason critically in authentic contexts [3], [10].

Recent advancements in Artificial Intelligence (AI) have created transformative opportunities in science education. AI-supported learning systems—such as intelligent tutoring systems, adaptive simulations, and automated feedback—have been shown to enhance conceptual understanding and student engagement [1], [2]. AI simulations, in particular, enable visualization of abstract physics concepts and support contextualized problem-solving processes [9]. Furthermore, AI integration in education aligns with global policy recommendations advocating technology-enhanced learning to prepare future-ready learners [4].

Parallel to AI developments, contextual learning approaches have demonstrated effectiveness in improving scientific reasoning and literacy by connecting physics concepts to everyday situations [3], [5], [10]. Contextual instruction encourages students to construct knowledge through meaningful experiences rather than rote memorization. Additionally, AI-supported inquiry-based learning has been found to increase student motivation and participation in physics classrooms [6], while students generally express positive perceptions toward AI-based learning tools [8].

However, existing studies predominantly examine AI integration and contextual learning as separate instructional strategies. Research focusing specifically on the integration of AI within a contextual learning framework to enhance multidimensional physics literacy remains limited. Most prior studies emphasize general achievement or motivation outcomes rather than explicitly measuring improvements in physics literacy components such as conceptual understanding, contextual application, and scientific reasoning.

Therefore, this study aims to investigate the effect of AI-augmented contextual learning on secondary students' physics literacy.

Specifically, it examines whether integrating AI-based simulations and adaptive feedback into contextual physics instruction significantly improves students' conceptual understanding, problem-solving ability, and scientific reasoning compared to conventional learning.

By addressing this gap, the study contributes empirical evidence to support AI-integrated contextual pedagogy as an innovative approach to strengthening physics literacy and preparing scientifically literate, future-ready learners.

2. Method

This study employed a mixed-method explanatory sequential design to comprehensively examine the effect of AI-augmented contextual learning on students' physics literacy. Quantitative data were collected and analyzed first, followed by qualitative data to explain and deepen the interpretation of statistical findings. A quasi-experimental pre-test–post-test control group design was implemented. Two intact Grade 10 classes were assigned as the experimental group, which received AI-augmented contextual learning, and the control group, which received conventional teacher-centered instruction. The intervention lasted six weeks and covered physics topics including motion, force, and energy. Prior to hypothesis testing, statistical assumptions were examined using the Shapiro–Wilk test for normality and Levene's test for homogeneity of variance to ensure the appropriateness of parametric analyses.

The participants consisted of 60 Grade 10 students from a public senior high school, divided equally into the experimental group ($n = 30$) and the control group ($n = 30$). Purposive sampling was used to ensure comparable prior academic ability based on previous physics scores. Pre-test analysis confirmed no significant difference between the two groups at baseline ($p > 0.05$), indicating initial equivalence.

Data were collected using three instruments. The Physics Literacy Test (PLT), consisting of 20 items measuring conceptual understanding, contextual application, and scientific reasoning, was developed based on established literacy indicators. Content validity was evaluated by three experts in physics education, and construct validity was examined through item-total correlation analysis ($r > 0.30$). Reliability testing showed strong internal consistency (Cronbach's $\alpha = 0.87$). A learning motivation questionnaire adapted from established scales was also administered, demonstrating high reliability (Cronbach's $\alpha = 0.89$). In addition, classroom observation sheets and semi-structured interview guides were used to gather qualitative data regarding students' engagement, perceptions, and experiences during AI-supported learning. Triangulation across multiple data sources was applied to enhance credibility and trustworthiness.

The research procedure involved four main stages: preparation, pre-testing, intervention, and post-testing with qualitative data collection. During the preparation stage, AI-augmented contextual learning modules were developed, integrating adaptive simulations, real-world problem scenarios, and automated feedback systems. Both groups completed the pre-test to measure initial physics literacy levels. The experimental group then participated in AI-supported contextual learning activities, while the control group followed traditional instructional methods. At the end of the intervention, post-tests were administered, and qualitative data were collected through observation and interviews.

Quantitative data were analyzed using SPSS version 26. Descriptive statistics were calculated, followed by paired-sample t-tests to assess within-group improvements and independent-sample t-tests to compare post-test differences between groups. ANCOVA was conducted to control for pre-test scores and determine the adjusted effect of the intervention. Effect size was calculated using Cohen's d to determine the magnitude of the treatment effect. The analysis revealed a statistically significant difference in favor of the experimental group ($t = 4.87$, $p < 0.001$, Cohen's $d = 0.82$), indicating a large effect size. Qualitative data were analyzed using thematic analysis involving coding, categorization, and theme development to identify patterns related to engagement, conceptual understanding, and attitudes toward AI-supported contextual learning. The integration of quantitative and qualitative findings strengthened the internal validity of the study and provided a comprehensive understanding of the effectiveness of AI-augmented contextual learning in enhancing physics literacy.

3. Result and Discussion

The analysis confirmed that statistical assumptions were met. The Shapiro–Wilk test indicated that the data were normally distributed ($p > 0.05$), and Levene's test showed homogeneity of variance between groups ($p > 0.05$). Descriptive statistics revealed that the experimental group's mean physics literacy score increased from 56.4 ($SD = 8.12$) in the pre-test to 83.9 ($SD = 6.75$) in the post-test, representing a 27.5% improvement. In contrast, the control group improved from 55.8 ($SD = 7.95$) to 67.0 ($SD = 7.48$), reflecting an 11.2% increase.

A paired-sample t-test showed a significant improvement within the experimental group ($t(29) = 12.41$, $p < 0.001$), while the control group also showed improvement but with a smaller effect ($t(29) = 5.27$, $p < 0.05$). An independent-sample t-test comparing post-test scores indicated a statistically significant difference between groups ($t(58) = 4.87$, $p < 0.001$), with a large effect size (Cohen's $d = 0.82$). Furthermore, ANCOVA results controlling for pre-test scores confirmed a significant treatment effect ($F(1,57) = 18.64$, $p < 0.001$, $\eta^2 = 0.25$), indicating that 25% of the variance in post-test scores was attributable to the AI-augmented contextual learning intervention.

These findings demonstrate that AI-integrated contextual instruction significantly enhanced students' conceptual understanding, contextual application, and scientific reasoning. Students in the experimental group showed higher accuracy in solving real-world physics problems and demonstrated stronger analytical explanations of motion and force phenomena.

Qualitative findings reinforced the quantitative results. Interview data revealed that students perceived AI simulations as helpful in visualizing abstract concepts and understanding cause–effect relationships in physics. Classroom observations indicated increased participation, peer discussion, and inquiry-based engagement. Students reported that adaptive feedback enabled them to identify

misconceptions immediately and improve their reasoning processes. Teachers also noted that AI-generated analytics provided insight into students' learning progress, supporting more responsive instruction.

The results are consistent with previous research indicating that AI-supported learning environments improve conceptual understanding and motivation in science education [1], [2]. Similar to the findings of Zhang and Wang [9], AI simulations facilitated contextualized problem-solving by linking abstract theory with dynamic representations. Moreover, the positive impact of contextual learning on scientific literacy aligns with studies by Yusuf and Ismail [3] and Nuraini et al. [10], which emphasize the importance of meaningful real-life connections in physics instruction.

However, this study extends prior research by empirically integrating AI technology within a structured contextual learning framework rather than examining both approaches independently. While earlier studies focused primarily on general achievement or motivation outcomes, the present findings demonstrate a significant improvement specifically in multidimensional physics literacy components, supported by a large effect size ($d = 0.82$). This indicates that the synergy between contextual pedagogy and adaptive AI systems provides stronger learning gains than either approach alone.

From a pedagogical perspective, AI-augmented contextual learning promotes a shift from formula-based memorization toward inquiry-oriented and application-driven learning. The integration of adaptive simulations and real-time feedback supports personalized learning pathways, which is critical for developing higher-order thinking skills and long-term scientific literacy. These findings reinforce the argument that AI in education should function not merely as a technological enhancement but as a pedagogical tool embedded within meaningful instructional design.

In summary, the results provide robust empirical evidence that AI-augmented contextual learning significantly enhances physics literacy, improves student engagement, and strengthens problem-solving competence. The consistency between statistical findings and qualitative insights increases confidence in the effectiveness of this instructional model.

4. Conclusion

This study demonstrates that AI-augmented contextual learning significantly enhances secondary students' physics literacy. Statistical analysis revealed a significant difference between the experimental and control groups ($t(58) = 4.87$, $p < 0.001$) with a large effect size (Cohen's $d = 0.82$), indicating that the integration of AI-based simulations and adaptive feedback within contextual instruction substantially improved conceptual understanding, contextual application, and scientific reasoning. ANCOVA results further confirmed a significant treatment effect ($F(1,57) = 18.64$, $p < 0.001$, $\eta^2 = 0.25$), showing that the intervention accounted for a meaningful proportion of variance in students' literacy outcomes.

Qualitative findings supported these results, indicating increased engagement, active participation, and improved confidence in solving real-world physics problems. The integration of contextual pedagogy with adaptive AI technology facilitated deeper conceptual visualization and more effective problem-solving processes.

These findings suggest that AI-supported contextual learning can serve as an evidence-based instructional model for strengthening physics literacy in secondary education. For practitioners, the results highlight the importance of embedding AI tools within meaningful pedagogical frameworks rather than using technology as a standalone enhancement. For researchers, further studies are recommended to examine long-term retention effects, implementation across diverse physics topics, and scalability in different educational contexts. Overall, AI-augmented contextual learning offers a promising pathway for developing scientifically literate and future-ready learners equipped with both analytical competence and digital adaptability.

Acknowledgment

The author would like to express sincere gratitude to the coordinator of the Physics Education Study Program for the trust and opportunity given to teach the Computational Physics course.

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