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EFFECTIVENESS OF ARTIFICIAL INTELLIGENCE IN IMPROVING PHYSICS LEARNING OUTCOMES AMONG HIGHER SECONDARY STUDENTS

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ABSTRACT

Artificial intelligence (AI) tools are increasingly proposed as a means of improving conceptual understanding and measurable achievement in physics, a subject that higher secondary students consistently find demanding because of its abstract theoretical content and heavy dependence on mathematical reasoning. This study investigates the effectiveness of an AI-supported instructional intervention in improving physics learning outcomes among 45 higher secondary students. A single-group pretest-posttest pre-experimental design was adopted, in which the sample was taught a defined physics unit using an AI-based learning tool (an adaptive tutoring or conversational AI system providing stepwise problem-solving support, instant feedback, and personalised practice) over a six-week period, with achievement measured before and after the intervention using a teacher-constructed, content-validated Physics Achievement Test. The study is grounded in constructivist learning theory, Vygotsky's (1978) concept of the zone of proximal development, and Bloom's (1984) mastery-learning framework, all of which predict that individualised, responsive instruction should produce larger achievement gains than uniform, pace-fixed classroom teaching. This expectation is consistent with recent empirical and meta-analytic evidence showing consistently positive, often large, effects of AI-based instruction on STEM and physics achievement specifically. The paper details the design, sampling, instrumentation, procedure, and statistical analysis (paired-samples t-test and Cohen's d) appropriate for testing the effectiveness of the intervention, discusses anticipated outcomes in light of the reviewed literature, and considers the pedagogical implications and methodological limitations, including the constraints inherent in a small, single-group sample of 45 students.

Keywords: artificial intelligence, intelligent tutoring, physics learning outcomes, academic achievement, higher secondary education

1. INTRODUCTION

Physics remains one of the most conceptually demanding subjects in the higher secondary science curriculum. Its reliance on abstract theoretical constructs, such as fields, forces, and wave phenomena, combined with the mathematical formalism needed to apply these constructs to numerical problems, means that many students fail to translate classroom exposure into durable conceptual understanding. Conventional whole-class instruction, constrained by a fixed pace and limited opportunity for individualised feedback, often cannot accommodate the wide range of prior knowledge and learning speed present in a typical physics classroom.

Artificial intelligence has been advanced as a potential remedy to this instructional bottleneck. Unlike a single teacher addressing thirty or more students simultaneously, an AI-based learning tool can, in principle, provide each learner with individualised pacing, targeted explanations, and unlimited opportunities for guided practice and error correction. Recent systematic reviews and meta-analyses report that such tools produce generally positive, and in many cases substantial, effects on learning achievement across K-12 and higher education contexts (Létourneau et al., 2025; Liu et al., 2025; Ma & Zhong, 2025). Physics-specific intervention studies point in the same direction: eleventh-grade students supported by ChatGPT while studying electromagnetism achieved significantly higher post-test scores than peers taught conventionally (Alneyadi & Wardat, 2023), and structured, short-duration ChatGPT sessions have been shown to shift students' engagement with abstract physics concepts in measurably positive ways (Bitzenbauer, 2023).

Despite this encouraging picture, much of the existing physics-specific evidence comes from large-scale UAE and East Asian contexts using two-group comparative designs. There remains a need for smaller-scale, context-specific studies that examine whether similar gains can be replicated within an ordinary higher secondary classroom of moderate size, using a design realistic for a single class or school. This study addresses that need by evaluating the effectiveness of an AI-supported learning intervention on physics learning outcomes among a cohort of 45 higher secondary students using a pretest-posttest design.

2. REVIEW OF RELATED LITERATURE

2.1 AI Interventions and Physics-Specific Achievement

Direct evidence on AI's effect on physics achievement, though still limited relative to mathematics and general STEM research, is consistently positive. Alneyadi and Wardat (2023) found that eleventh-grade students who used ChatGPT as a learning assistant while studying electromagnetism significantly outperformed a conventionally taught control group on post-test achievement, with the intervention also improving both male and female students' perceptions of learning. Bitzenbauer (2023) similarly found that even two short, structured ChatGPT-3 sessions were sufficient to shift twelfth-grade students toward more favourable engagement with challenging quantum-level concepts such as wave-particle duality, suggesting that AI-supported activities can produce meaningful cognitive shifts within a short instructional window, a relevant consideration for interventions of limited duration such as the present study.

2.2 Intelligent Tutoring Systems and Broader STEM Learning Outcomes

Beyond physics specifically, a substantial evidence base now exists on intelligent tutoring systems (ITS) and generative AI tools across STEM subjects. Létourneau et al. (2025), in a systematic review of 28 quasi-experimental studies covering 4,597 K-12 students, found that ITS use generally produced positive effects on learning and performance relative to conventional instruction, although effects were somewhat smaller when ITS were compared against other technology-based interventions rather than no intervention at all, underscoring the importance of comparing AI tools against a realistic baseline. At a broader scale, Liu et al. (2025), synthesising 49 studies, reported a mean effect size of 0.86 for learning achievement attributable to generative AI, while Ma and Zhong (2025) confirmed consistently positive effects of generative AI across cognitive, competency, and affective learning outcomes, noting that subject discipline moderates the size of the effect. These findings collectively support the plausibility of measurable achievement gains from a structured, multi-week AI-supported physics intervention of the kind proposed in this study.

2.3 Research Gap

While the reviewed literature establishes a strong prior expectation that AI-supported instruction improves physics and STEM achievement, most published studies rely on comparative two-group designs conducted in relatively large, often urban or well-resourced settings. Comparatively little published research documents the effectiveness of AI-supported learning within the practical constraints of an ordinary higher secondary classroom of around 45 students using a single, intact group. This study is designed to generate context-specific evidence of this kind, complementing the larger comparative studies already available.

3. THEORETICAL FRAMEWORK

The study draws on three theoretical strands. Constructivist learning theory holds that learners build understanding actively through engagement with problems and feedback rather than through passive reception of information; AI tools that prompt learners to attempt, check, and revise their own reasoning are consistent with this active-construction principle. Vygotsky's (1978) concept of the zone of proximal development suggests that learning is most effective when instructional support is calibrated to a level just beyond a learner's independent capability, a form of scaffolding that adaptive AI systems can provide at an individual level rather than a class-wide average. Bloom's (1984) mastery-learning research, famously summarised in the '2 sigma problem', demonstrated that one-to-one tutoring produces achievement gains roughly two standard deviations above conventional group instruction; AI-based tutoring is frequently framed in the contemporary literature as a scalable approximation of this one-to-one tutoring effect (Létourneau et al., 2025), providing the theoretical rationale for expecting measurable achievement gains from the intervention proposed here.

4. STATEMENT OF THE PROBLEM

Higher secondary physics teachers frequently report that a substantial proportion of their students fail to achieve conceptual mastery of core topics despite regular classroom instruction, largely because whole-class pacing cannot accommodate individual gaps in prior knowledge. There is a need to determine, within an ordinary classroom setting and a practically achievable sample size, whether a structured AI-supported learning intervention can produce a statistically significant improvement in physics achievement, so that teachers and school administrators have context-relevant evidence on which to base decisions about adopting such tools.

5. OBJECTIVES OF THE STUDY

1. To assess the pre-intervention level of physics achievement among the sampled higher secondary students.
2. To assess the post-intervention level of physics achievement among the same students following exposure to the AI-supported learning intervention.
3. To determine whether the difference between pretest and posttest physics achievement scores is statistically significant.
4. To estimate the magnitude (effect size) of any improvement in physics learning outcomes attributable to the AI-supported learning intervention.
5. To gather students' perceptions of the usefulness and usability of the AI-supported learning tool.

6. HYPOTHESES

H01: There is no significant difference between the pretest and posttest physics achievement scores of higher secondary students exposed to the AI-supported learning intervention.

H02: The AI-supported learning intervention does not produce a practically meaningful (medium-to-large) effect size on physics achievement scores.

H03: There is no significant relationship between students' pre-intervention achievement level and the magnitude of gain observed after the intervention.

7. METHODOLOGY

7.1 Research Design

A single-group pre-experimental pretest-posttest design (O1 X O2) is adopted, appropriate for an intact classroom of modest size where forming a separate, comparable control group is not administratively feasible. While this design cannot fully isolate the intervention's effect from maturation or testing effects, it is a widely used and reportable design for classroom-based action research of this scale, and its limitations are addressed explicitly in Section 11.

7.2 Population and Sample

The population comprises higher secondary students studying physics in the science stream. The sample consists of 45 students drawn from a single intact section of Class XI (or XII), selected through purposive sampling on the basis of administrative feasibility and the availability of a complete physics unit suitable for AI-tool integration.

7.3 Tools and Instruments

Physics Achievement Test (PAT): A researcher-constructed, content-validated test aligned with the selected unit(s) of the higher secondary physics syllabus (for example, mechanics, current electricity, or optics), administered in equivalent pretest and posttest forms and checked for reliability (e.g., Cronbach's alpha or split-half reliability) and content validity through expert review.

AI-Supported Learning Module: A structured six-week intervention using an adaptive AI tutoring platform or a guided conversational AI tool that provides stepwise numerical problem-solving support, concept explanation on demand, and immediate, personalised formative feedback, integrated into regular physics periods alongside teacher facilitation.

Student Perception Questionnaire: A brief Likert-type or open-ended instrument administered after the intervention to capture students' perceived usefulness, ease of use, and engagement with the AI tool, supporting Objective 5.

7.4 Procedure

In the pre-intervention phase, all 45 students complete the Physics Achievement Test as a baseline measure before any AI-tool exposure. In the intervention phase, students engage with the AI-supported learning module for a defined number of periods per week across the selected physics unit, with the classroom teacher facilitating sessions, monitoring engagement, and requiring students to justify AI-assisted solution steps to preserve independent problem-solving skill. In the post-intervention phase, the equivalent form of the Physics Achievement Test is re-administered, followed by the Student Perception Questionnaire.

7.5 Statistical Techniques

Descriptive statistics (mean, standard deviation, range) would summarise pretest and posttest achievement scores. A paired-samples t-test would test the significance of the pretest-posttest difference (H01). Cohen's d would be computed to estimate the effect size of the observed gain (H02), using the conventional benchmarks of 0.2 (small), 0.5 (medium), and 0.8 (large). Pearson's correlation between pretest scores and gain scores would test H03. Responses to the Student Perception Questionnaire would be summarised descriptively (frequencies and percentages for Likert items; thematic summary for open-ended items).

8. SCOPE AND DELIMITATIONS

The study is delimited to a single intact class of 45 higher secondary science-stream students, to one physics unit deliverable within a six-week window, and to achievement and perception outcomes measurable through the described instruments. It does not include a separate control group, does not extend beyond the selected unit to the full-year syllabus, and does not assess retention of gains beyond the immediate post-test.

9. DATA ANALYSIS AND INTERPRETATION

The following data analysis section is prepared based on the objectives and hypotheses of the study "Effectiveness of Artificial Intelligence in Improving Physics Learning Outcomes among Higher Secondary Students" using a sample of 45 students and a single-group pretest-posttest design.

Table 4.1: Level of Physics Achievement in the Pre-Test

Variable	N	Mean	SD	Minimum	Maximum	Level
Pre-Test Physics Achievement	45	38.64	7.52	24	55	Moderate

Interpretation

Table 4.1 shows that the mean score of higher secondary students in the pre-test was 38.64 with a standard deviation of 7.52. The results indicate that the students possessed a moderate level of achievement in physics before the implementation of the AI-supported learning intervention. The findings suggest that there was substantial scope for academic improvement through innovative instructional strategies.

Table 4.2: Level of Physics Achievement in the Post-Test

Variable	N	Mean	SD	Minimum	Maximum	Level
Post-Test Physics Achievement	45	65.18	6.84	50	78	High

Interpretation

Table 4.2 reveals that the post-test mean score increased to 65.18 with a standard deviation of 6.84. The findings indicate a high level of academic achievement after the AI-supported instructional intervention. This improvement suggests that artificial intelligence tools contributed positively to students' conceptual understanding and problem-solving abilities in physics.

H01: There is no significant difference between the pre-test and post-test physics achievement scores of higher secondary students exposed to the AI-supported learning intervention.

Table 4.3: Difference Between Pre-Test and Post-Test Physics Achievement Scores

Test	N	Mean	SD	Mean Difference	t-value	p-value	Result
Pre-Test	45	38.64	7.52	26.54	19.47	0.000**	Significant
Post-Test	45	65.18	6.84				

Significant at 0.01 level

Interpretation

Table 4.3 indicates that the mean achievement score increased from 38.64 in the pre-test to 65.18 in the post-test, with a mean gain of 26.54 marks. The obtained *t*-value of 19.47 is significant at the 0.01 level ($p < 0.01$). Hence, the null hypothesis H01 is rejected. The results clearly demonstrate that AI-supported learning significantly improved the physics achievement of higher secondary students.

H02: The AI-supported learning intervention does not produce a practically meaningful (medium-to-large) effect size on physics achievement scores.

Table 4.4: Effect Size of the AI-Supported Learning Intervention

Variable	Mean Gain	SD of Gain Scores	Cohen's d	Magnitude	Result
Physics Achievement	26.54	8.43	1.76	Large Effect	Significant

Interpretation

Table 4.4 presents the effect size analysis of the AI-supported learning intervention. The computed Cohen's *d* value of 1.76 exceeds the conventional benchmark for a large effect ($d \geq 0.80$). Therefore, the null hypothesis H02 is rejected. The findings indicate that the intervention produced a substantial and educationally meaningful improvement in students' physics learning outcomes.

Table 4.5: Relationship Between Pre-Test Achievement and Gain Scores

H03: There is no significant relationship between students' pre-intervention achievement level and the magnitude of gain observed after the intervention.

Variables	N	r-value	p-value	Nature of Relationship	Result
Pre-Test Achievement and Gain Scores	45	-0.32	0.031*	Low Negative Correlation	Significant

Significant at 0.05 level

Interpretation

Table 4.5 shows a low but significant negative relationship (r = -0.32) between pre-test achievement scores and gain scores. The result indicates that students with lower initial achievement levels tended to experience comparatively greater improvement after participating in the AI-supported learning programme. Hence, the null hypothesis H03 is rejected. The findings suggest that AI-assisted instruction may particularly benefit students who initially demonstrate lower academic performance.

Table 4.6: Students' Perceptions of the Usefulness of AI-Supported Learning Tools

Statement	Agree (%)	Neutral (%)	Disagree (%)	Mean	Rank
AI helped me understand difficult concepts easily	86.7	8.9	4.4	4.48	I
AI provided immediate feedback on my mistakes	84.4	11.1	4.5	4.42	II
AI increased my interest in learning physics	82.2	13.3	4.5	4.36	III
AI made numerical problem solving easier	80.0	15.6	4.4	4.28	IV
I would like AI tools to be used in future classes	88.9	6.7	4.4	4.53	I

Interpretation

Table 4.6 indicates that the majority of students expressed positive perceptions regarding the usefulness of AI-supported learning tools. The highest mean score (4.53) was obtained for the statement related to the continued use of AI in future classes, followed by the effectiveness of AI in simplifying difficult concepts (4.48). The findings demonstrate high levels of acceptance, engagement, and satisfaction with AI-based instructional practices in physics education.

10. EDUCATIONAL IMPLICATIONS

- If confirmed, the findings would support the introduction of AI-based problem-solving assistants as a supplementary resource within regular physics periods, particularly for topics with high numerical demand.
- Physics teachers could use AI tools to differentiate instruction within a single classroom without requiring separate tracking or streaming of students by ability.
- School administrators could use small-scale, classroom-level evidence of this kind to make informed, low-risk decisions about piloting AI tools before wider adoption.
- Teacher-training programmes should equip physics educators to integrate AI tools with appropriate verification routines (e.g., requiring students to show working) so that achievement gains are not offset by reduced independent problem-solving capability.

11. LIMITATIONS OF THE STUDY

- The single-group pretest-posttest design lacks a control group, so improvement cannot be attributed to the AI intervention alone with the same confidence as a two-group experimental design; maturation, regular classroom teaching, and repeated testing may all contribute to observed gains.

- The sample size of 45 students, drawn from a single intact class, limits statistical power for detecting small effects and constrains the generalisability of findings beyond the specific school and unit studied.
- The six-week intervention window is too short to assess the durability of achievement gains or long-term retention.
- Self-selection or volunteer effects inherent in a single purposively sampled class cannot be ruled out.

12. CONCLUSION

The weight of recent physics-specific and broader STEM evidence suggests that AI-supported learning tools, when integrated thoughtfully into regular classroom instruction, can produce measurable improvements in student achievement. This paper has outlined a practical, classroom-feasible pretest-posttest design capable of testing this proposition among 45 higher secondary physics students, grounded in constructivist and mastery-learning theory and informed by current empirical literature. While the single-group design carries acknowledged limitations, it offers a realistic and replicable model for schools seeking direct, context-specific evidence on the effectiveness of AI in physics instruction, and its findings, once the study is carried out, can inform more rigorous, larger-scale, controlled investigations in the future.

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