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Research Article

PhET: SIMULATIVE PEDAGOGY IN TEACHING PHYSICS

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Abstract

Physics is often perceived as a difficult subject due to its abstract nature and reliance on higher-order cognitive skills. This study investigated the effectiveness of PhET Interactive Simulations in enhancing Grade 9 learners' conceptual understanding in Physics across knowledge, analysis, and evaluation domains. A quasi-experimental pretest–posttest control group design was employed involving 42 learners from Corella National High School, Bohol, Philippines. The control group received traditional instruction, while the experimental group was exposed to PhET simulation-based instruction over four weeks. Data were gathered using a validated 48-item test and a 20-item perception questionnaire. Results revealed that both groups showed significant improvement; however, the experimental group demonstrated substantially higher gains across all cognitive domains, particularly in analysis and evaluation. Learners also reported strong perceptions of usefulness ($M = 4.31$) and ease of use ($M = 4.31$) of the simulations. Furthermore, a significant moderate positive correlation was found between learners' perceptions and posttest performance ($r = 0.319$, $p < 0.05$). Findings indicate that PhET simulations significantly enhance conceptual understanding and support higher-order thinking skills more effectively than traditional instruction. The study recommends integrating simulation-based pedagogy to improve physics learning outcomes and learner engagement.

Keywords: PhET Interactive Simulations, Physics Education, Conceptual Understanding, Higher-Order Thinking Skills, Quasi-Experimental Design, Technology-Enhanced Learning, Constructivist Learning, Bloom's Taxonomy, Student Perception; Secondary Education.

INTRODUCTION

Physics is widely recognized as one of the most challenging subjects in secondary education due to its abstract concepts, mathematical demands, and need for strong visualization skills. Many learners struggle to internalize these concepts, resulting in persistent misconceptions and fragmented understanding that hinder their ability to apply, analyze, and evaluate scientific phenomena. These learning difficulties are not only global but also evident in the Philippine educational context, where students frequently encounter challenges in understanding abstract physics topics. Traditional lecture-based and textbook-centered instruction, while widely practiced, often fails to address deep conceptual gaps and does not sufficiently support higher-order thinking. Contemporary science education emphasizes the development of cognitive skills across multiple domains, particularly knowledge, analysis, and evaluation, as framed in the Revised Bloom's Taxonomy. Knowledge serves as the foundation for learning, enabling learners to recall and understand essential concepts. Analysis allows students to examine relationships, interpret data, and break down complex information, while evaluation involves making judgments based on evidence and criteria skills essential for scientific reasoning and problem-solving. Together, these domains reflect a progression from basic understanding to higher-order thinking. However, research in physics education suggests that students' difficulties often stem not from lack of exposure to content but from challenges in organizing and processing knowledge meaningfully, which limits their ability to solve problems and reason scientifically. To address these challenges, educational research highlights the importance of learner-centered and technology-enhanced instructional approaches.

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Among these, PhET Interactive Simulations have gained significant attention as innovative tools for teaching physics. Developed as research-based interactive simulations, PhET allows learners to visualize abstract phenomena, manipulate variables, and explore scientific relationships in a dynamic and inquiry-based environment. These features align with the need to make physics concepts more accessible and engaging, particularly for learners who struggle with traditional instructional methods. The present study is anchored on several theoretical perspectives that explain how simulation-based instruction can enhance learning. Constructivist Learning Theory posits that learners actively construct knowledge through interaction and experience. This perspective is reflected in the use of PhET simulations, which encourage exploration, experimentation, and collaboration. Complementing this, the Revised Bloom's Taxonomy provides a framework for assessing cognitive development across knowledge, analysis, and evaluation, which are central to this study. The Cognitive Theory of Multimedia Learning further explains that learning is more effective when information is presented through both visual and verbal channels, enabling learners to process and integrate knowledge more efficiently. Additionally, the Technology Acceptance Model (TAM) highlights that learners' engagement with technology is influenced by their perceptions of its usefulness and ease of use, making these factors important in understanding the effectiveness of simulation-based instruction. Empirical evidence from international studies consistently supports the effectiveness of simulation-based learning in physics education. Research conducted in various countries has shown that PhET simulations improve students' conceptual understanding, engagement, and academic performance. Studies demonstrate that learners who use simulations perform significantly better in posttests compared to those taught through traditional methods, particularly when simulations are integrated with active learning strategies. Furthermore, simulations enable learners to manipulate variables, test hypotheses, and observe outcomes in real time, fostering deeper conceptual understanding and critical thinking. Meta-analytical findings also indicate that computer-based simulations enhance learning outcomes across diverse contexts by providing interactive, safe, and repeatable learning environments.

In addition to cognitive benefits, studies grounded in technology acceptance frameworks reveal that learners generally perceive PhET simulations as useful and easy to use, which positively influences their motivation and engagement. These perceptions are important because they contribute to how effectively learners interact with the technology and ultimately impact learning outcomes. Research further shows that simulation-based instruction promotes positive attitudes toward physics, increases motivation, and enhances problem-solving skills.

In the Philippine context, existing studies similarly highlight the potential of PhET simulations and other innovative instructional strategies in improving physics education. Research conducted among secondary and tertiary learners indicates that students exposed to simulation-based instruction demonstrate higher levels of conceptual understanding and academic performance compared to those receiving traditional instruction. Studies also show that simulations enhance learners' confidence, engagement, and attitudes toward physics. Moreover, inquiry-based and metacognitive approaches integrated with simulations have been found to further strengthen conceptual understanding and promote reflective thinking. Despite these promising findings, gaps remain in the literature. Many studies focus primarily on overall academic performance or general conceptual understanding without examining specific cognitive domains such as knowledge, analysis, and evaluation simultaneously. Additionally, limited research has explored how learners' perceptions of technology particularly perceived usefulness and perceived ease of use relate to their learning outcomes, especially within the Philippine secondary education context. This gap is significant because understanding both cognitive and affective dimensions of learning can provide a more comprehensive evaluation of instructional effectiveness. Given these considerations, there is a need to further investigate how simulation-based pedagogy, specifically through PhET Interactive Simulations, influences learners' conceptual understanding across different cognitive domains while also examining their perceptions of the technology. Addressing this gap is essential for developing evidence-based instructional strategies that enhance both learning outcomes and student engagement in physics education.

Thus, this study aims to investigate the effectiveness of PhET simulation-based instruction in optimizing Grade 9 learners' conceptual understanding in physics. Specifically, it seeks to determine the level of learners' pretest and posttest performance in terms of knowledge, analysis, and evaluation; examine the significant differences between the control and experimental groups; assess learners' perceptions of PhET simulations in terms of perceived usefulness and perceived ease of use; analyze the relationship between learners' posttest performance and their perceptions; and propose an instructional action plan to improve the teaching and learning of physics concepts.

METHODOLOGY

This study employed a quasi-experimental pretest–posttest control group design to examine the effectiveness of PhET simulation-based instruction in improving Grade 9 learners' conceptual understanding of physics. Two intact classes from Corella National High School, Bohol, Philippines, were purposively selected and assigned as the control group (standard classroom instruction) and the experimental group (PhET simulation-based instruction), with 21 learners in each group ($N = 42$). Selection criteria included comparable academic performance, class size, and schedule to ensure group equivalence. The intervention was conducted over four weeks during the fourth grading period of Academic Year 2025–2026, covering selected Grade 9 Physics Most Essential Learning Competencies (MELCs), including projectile motion, momentum and collisions, and conservation of energy. Both groups received the same content, differing only in instructional approach. The experimental group utilized PhET simulations (e.g., Projectile Motion, Collision Lab, Energy Skate Park), while the control group used traditional lecture-based and activity-centered instruction.

Data were collected using two validated instruments: (1) a 48-item researcher-made multiple-choice test measuring conceptual understanding across knowledge, analysis, and evaluation domains, administered as both pretest and posttest; and (2) a 20-item Likert-scale questionnaire assessing the experimental group's perceptions of PhET simulations in terms of Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). Instruments underwent expert validation and pilot testing to ensure reliability and content validity. Descriptive statistics (mean, standard deviation, frequency, and percentage) were used to summarize performance and perception data. Inferential statistics included the paired samples t-test to determine significant differences between pretest and posttest scores within groups, and Pearson's product–moment correlation (r) to examine the relationship between learners' posttest performance and their perceptions of PhET simulations. Ethical standards were strictly observed, including informed consent, voluntary participation, confidentiality, and institutional approval. Findings served as the basis for proposing an instructional action plan to enhance physics teaching using simulation-based pedagogy.

RESULTS AND DISCUSSION

This section presents, analyzes, and interprets the data gathered to determine the effectiveness of PhET simulation-based instruction in enhancing learners' conceptual understanding of physics. The pretest results of both the control and experimental groups revealed that learners were consistently classified under the Beginning level across knowledge, analysis, and evaluation domains. This indicates uniformly low prior conceptual understanding and confirms baseline equivalence between groups. Establishing this homogeneity strengthens the internal validity of the study, as any observed post-intervention differences can be attributed to the instructional treatments rather than pre-existing disparities.

Posttest Performance and Comparative Outcomes

Following the intervention, contrasting patterns emerged between the two groups. The control group exhibited only modest improvements, with mean scores increasing slightly but remaining largely within the lower proficiency levels. Gains were more noticeable in knowledge and evaluation, while analytical skills showed minimal development, suggesting that traditional instruction had limited effectiveness in fostering higher-order thinking. In contrast, the experimental group demonstrated substantial improvements across all domains. Learners progressed to higher proficiency levels, particularly in analysis and evaluation, indicating enhanced ability to interpret, apply, and critically assess physics concepts. The notable increase in overall mean scores reflects the effectiveness of PhET simulations in promoting deeper conceptual understanding. These findings align with constructivist learning theory, which posits that active engagement and interactive environments facilitate meaningful knowledge construction.

Inferential Analysis of Learning Gains

To determine whether the observed improvements were statistically significant, paired-samples t-tests were conducted. For the control group, results showed statistically significant differences between pretest and posttest scores in all domains: knowledge ($t = -5.01$, $p = 0.006$), analysis ($t = -3.06$, $p = 0.003$), and evaluation ($t = -2.38$, $p = 0.020$). However, the magnitude of these gains was relatively small, particularly in analysis (MD = 2.37), indicating limited practical significance despite statistical improvement. For the experimental group, the results revealed highly significant and substantially larger gains: knowledge ($t = -8.84$, $p = 0.0036$, MD = 12.9), analysis ($t = -8.00$, $p = 0.00016$, MD = 17.0), and evaluation ($t = -2.00$, $p = 0.049$, MD = 9.4). The large mean differences and strong statistical significance indicate that PhET simulation-based instruction had a pronounced effect on learners' conceptual understanding, particularly in developing higher-order cognitive skills. Comparatively, the experimental group outperformed the control group across all domains, providing robust evidence that simulation-based pedagogy is more effective than traditional instruction. The substantial improvement in analytical skills is especially noteworthy, as this domain remained largely unchanged in the control group.

Learners' Perceptions of PhET Simulations

Learners' perceptions were assessed using the constructs of Perceived Usefulness (PU) and Perceived Ease of Use (PEOU).

Table 1. Perceived Usefulness of PhET Simulations

Indicator	Weighted Mean	Interpretation
Helps understand lessons better	4.50	Strongly Agree
Easier understanding of difficult topics	3.90	Agree
Visualizes abstract concepts	4.10	Agree
Improves performance in activities	4.50	Strongly Agree
Aids completion of assignments	4.30	Strongly Agree
Enhances learning speed	4.25	Strongly Agree
Improves problem-solving accuracy	4.45	Strongly Agree
Supports retention	4.10	Agree
Connects learning to real life	4.25	Strongly Agree
Overall usefulness	4.70	Strongly Agree
Overall Mean	4.31	Strongly Agree

The overall mean of 4.31 indicates that learners perceived PhET simulations as highly beneficial. The highest-rated indicators highlight improved understanding, performance, and real-life application of concepts, suggesting that simulations effectively bridge abstract and concrete learning.

Table 2. Perceived Ease of Use of PhET Simulations

Indicator	Weighted Mean	Interpretation
Easy to use	4.10	Agree
Controls are understandable	4.30	Strongly Agree
Instructions are clear	4.60	Strongly Agree
Easy navigation	4.10	Agree
Can be used independently	4.05	Agree
Builds confidence	4.25	Strongly Agree
Not complicated	4.30	Strongly Agree
Usable even with low tech skills	4.30	Strongly Agree
Enjoyable to use	4.55	Strongly Agree
Overall ease of use	4.55	Strongly Agree
Overall Mean	4.31	Strongly Agree

Similarly, the overall mean of 4.31 reflects that learners found the simulations highly accessible and user-friendly. High ratings in clarity, usability, and enjoyment indicate that the technology reduced cognitive load and allowed learners to focus on conceptual understanding rather than operational difficulty.

Relationship between Perceptions and Performance

Further analysis revealed a statistically significant moderate positive correlation between learners' posttest scores and their perceptions of PhET simulations ($r = 0.319$, $p = 0.045$). This indicates that learners who perceived the simulations as useful and easy to use tended to achieve higher academic performance. This finding supports the Technology Acceptance Model, which posits that perceived usefulness and ease of use influence engagement and learning outcomes. Positive perceptions likely enhanced motivation, leading to increased interaction with the simulations and deeper cognitive processing. The findings collectively demonstrate that while traditional instruction can produce statistically significant improvements, its impact is limited, particularly in developing higher-order thinking skills. In contrast, PhET simulation-based instruction yields substantial and meaningful gains across all cognitive domains. The integration of interactive simulations not only enhances conceptual understanding but also promotes learner engagement, autonomy, and positive attitudes toward learning. The significant relationship between perception and performance further emphasizes that effective learning technologies must be both pedagogically sound and user-friendly. Overall, the results provide strong empirical evidence supporting the adoption of simulation-based pedagogy as an effective strategy for improving physics education outcomes, particularly in fostering analytical and evaluative competencies.

Conclusion

The results of this study provide clear and compelling evidence that PhET simulation-based instruction is an effective approach for enhancing conceptual understanding in Physics. While both the control and experimental groups began with similarly low levels of prior knowledge and higher-order thinking skills, only the group exposed to simulations demonstrated substantial and meaningful improvement across the domains of knowledge, analysis, and evaluation. This indicates that traditional instruction alone may be insufficient in developing deeper conceptual understanding, particularly in higher-order cognitive skills. Furthermore, the overwhelmingly positive learner perceptions in terms of usefulness and ease of use highlight the accessibility and instructional value of PhET simulations. These favorable perceptions are not merely attitudinal; they are significantly associated with improved academic performance. The moderate positive correlation between learners' perceptions and their posttest scores suggests that when students view a learning tool as beneficial and easy to use, they are more likely to engage with it effectively and achieve better outcomes. Overall, the study confirms that PhET simulations serve as a powerful pedagogical tool that not only improves conceptual understanding but also enhances learner engagement and motivation. The integration of simulation-based instruction in Physics education is therefore strongly recommended, particularly for fostering higher-order thinking skills and addressing the limitations of traditional teaching methods.

Recommendations

Based on the findings, it is recommended that PhET simulations be integrated into physics instruction as a complement to traditional teaching, particularly for abstract concepts. Teachers are encouraged to adopt simulation-based and inquiry-driven strategies to enhance learners' higher-order thinking skills, including analysis and evaluation. To support this, educational institutions should provide professional development programs that equip teachers with the competencies needed to effectively utilize digital simulations. School administrators should ensure the availability of adequate technological resources, such as devices and reliable internet access, to facilitate implementation. Curriculum developers are also encouraged to incorporate interactive simulations into instructional materials to promote engagement and conceptual understanding. Future research may examine the long-term effects of simulation-based instruction and its applicability across different disciplines and learner groups. Additionally, educators should consider learners' perceptions, as positive attitudes toward usefulness and ease of use significantly influence engagement and academic performance.

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