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THE EFFECT OF PHET SIMULATION-BASED LEARNING ON STUDENTS' CONCEPTUAL UNDERSTANDING IN PHYSICS

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ABSTRACT

PhET simulation-based learning represents an important aspect of physics education because it addresses persistent challenges related to students' low conceptual understanding and the abstract nature of many physics topics. This issue highlights the need for further investigation into the effectiveness of interactive digital media in improving students' conceptual mastery. This study aims to analyze the effect of PhET simulation-based learning on students' conceptual understanding in physics. The research employed a quantitative approach with a quasi-experimental method, using a non-equivalent control group design. Data were collected through pre-test and post-test instruments to measure students' conceptual understanding. The collected data were analyzed using descriptive statistics, N-gain analysis, and an independent sample t-test. The results indicate that students in the experimental class experienced a significant improvement, with mean scores increasing from 61.20 to 83.45 and an N-gain value of 0.70 (high category), while the control class showed an increase from 60.75 to 71.30 with an N-gain value of 0.35 (medium category). Furthermore, the independent sample t-test yielded a significance value of 0.000 < 0.05, confirming a statistically significant difference between the two groups. These findings demonstrate that PhET simulation-based learning effectively enhances students' conceptual understanding by facilitating interactive visualization and promoting active learning. This study contributes significantly to the advancement of physics education at both national and international levels by offering an innovative instructional strategy grounded in digital technology integration. Additionally, the findings are expected to serve as a valuable reference for future research, particularly in the areas of technology-enhanced learning and conceptual understanding in physics, and to encourage more in-depth and applied studies in related fields.

Keywords: PhET Simulation, Conceptual Understanding, Physics Education, Interactive Learning, Quasi-Experimental Design.

INTRODUCTION

Physics education plays a strategic role in fostering students' conceptual understanding, analytical thinking, and scientific reasoning skills. However, at the local, national, and international levels, numerous studies indicate that students continue to face difficulties in comprehending abstract physics concepts, such as force, motion, and energy. These challenges contribute to low academic achievement and the persistence of misconceptions. Recent research has shown that conventional instructional approaches, which predominantly emphasize lectures and mathematical problem-solving, are less effective in promoting deep conceptual understanding (Zulkarnain et al., 2023). Meanwhile, despite the rapid advancement of digital technologies,

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the integration of interactive learning media in physics classrooms remains limited, particularly in developing countries, even though such media hold substantial potential to enhance conceptual learning.

From the researcher's perspective, the limited use of interactive learning media reflects a gap between pedagogical theory and classroom practice. Drawing on constructivist theory proposed by Piaget and further developed by Vygotsky (1978), learning is most effective when students actively construct knowledge through interaction with their learning environment. In the context of physics education, abstract concepts require visualization and experimental experiences to be meaningfully understood (Magfirah, 2024). Therefore, learning environments that enable students to manipulate variables and observe phenomena dynamically are essential. Interactive simulations, such as PhET, are well aligned with these principles, as they facilitate active, exploratory, and experience-based learning, making them highly relevant for further investigation.

Previous studies have explored various innovative approaches in physics education, including inquiry-based learning, problem-based learning, and the use of interactive media. Research conducted by Sabaryati et al. (2021) demonstrated that project-based and interactive learning media positively influence students' motivation and conceptual understanding (M. F. N. M. Utami et al., 2023). In addition, Zulkarnain et al. (2024) highlighted the effectiveness of virtual laboratories in enhancing student engagement in physics learning. Nevertheless, most prior studies have primarily focused on learning outcomes or general conceptual understanding, while investigations integrating the effects of instructional media on science process skills and critical thinking remain limited (V. Utami et al., 2025). Furthermore, empirical studies specifically examining the use of PhET simulations to improve conceptual understanding in comparison with conventional instruction are still scarce, indicating a clear research gap.

This study offers novelty by specifically examining the impact of PhET simulations on students' conceptual understanding in physics, grounded in constructivist theory and the Cognitive Theory of Multimedia Learning. According to Mayer (2009), learning is more effective when information is presented through a combination of verbal and visual representations simultaneously (Amir et al., 2026). PhET simulations integrate animations, interactive controls, and real-time feedback, enabling dual-channel cognitive processing while reducing cognitive load. Accordingly, this study not only evaluates the effectiveness of instructional media in improving learning outcomes but also provides deeper insights into how interactive simulations support meaningful conceptual construction (Purwana et al., 2025).

Based on these considerations, this study focuses on the use of PhET simulations as an instructional medium in physics learning and its effect on students' conceptual understanding. The primary objective is to analyze the influence of PhET simulation-based learning on students' physics conceptual understanding compared to conventional instructional methods. The findings of this study are expected to contribute to the development of more effective physics learning strategies and to provide practical guidance for educators in integrating digital technology into physics instruction.

RESEARCH METHOD

This study employed a quantitative approach using an experimental method to examine the effect of PhET simulation-based learning on students' conceptual understanding in physics. A quantitative approach was selected as it enables the measurement of relationships between variables and the determination of the magnitude of the independent variable's influence, namely PhET simulations, on the dependent variable, namely students' conceptual understanding, under controlled conditions and objective analysis (Hamdi, 2015). The research design applied was a quasi-experimental design, specifically the non-equivalent control group design, which involved two groups: an experimental group and a control group (Kenny, 1975). The experimental group received instruction using PhET simulations, while the control group was taught through conventional methods. Both groups were administered a pre-test prior to the treatment and a post-test after the treatment to assess students' conceptual understanding, with the differences in scores used to determine the effectiveness of the intervention.

The participants in this study were senior high school students (e.g., grade X) from a selected school. The sampling technique employed was purposive sampling, in which participants were selected based on specific criteria relevant to the research objectives, such as similar academic ability and learning background (Susanti, 2005). Two classes were chosen as research samples, with one designated as the experimental group and the other as the control group, in order to ensure comparability between groups and to minimize potential bias. The primary research instrument was a conceptual understanding test in the form of multiple-choice questions accompanied by reasoning (two-tier or four-tier diagnostic test), designed to measure students' conceptual comprehension and identify potential misconceptions (Fadlan et al., 2024). In addition, observation sheets were utilized to monitor the implementation of the learning process. Data collection was conducted through the administration of pre-tests and post-tests, as well as classroom observations during the treatment. Prior to implementation, the instruments were subjected to validity and reliability testing to ensure their appropriateness for data collection.

The collected data were analyzed using both descriptive and inferential statistical techniques. Descriptive statistics, including mean and standard deviation, were used to summarize the distribution of students' scores. Inferential analysis involved prerequisite tests, namely normality and homogeneity tests, to ensure that the data met the assumptions for further statistical procedures. Hypothesis testing was conducted using an independent sample t-test to determine whether there was a statistically significant difference between the experimental and control groups. Additionally, the normalized gain (N-gain) was calculated to evaluate the effectiveness of the PhET simulation in improving students' conceptual understanding.

RESULTS AND DISCUSSION

This section presents the research findings derived from the implementation of PhET simulation-based learning in the experimental class and conventional instruction in the control class. The findings are systematically organized in accordance with the research focus, namely students' conceptual understanding of physics, and are subsequently analyzed using statistical techniques and interpreted by linking them to relevant learning theories and prior studies. Accordingly, this results and discussion section not only reports empirical evidence but also provides a comprehensive scientific interpretation of the effectiveness of interactive simulations in physics learning.

Furthermore, based on the pre-test and post-test results, an improvement in students' conceptual understanding was observed in both groups, albeit at different magnitudes. In the experimental class, the mean pre-test score of 61.20 increased to 83.45 in the post-test, reflecting a gain of 22.25 points. In contrast, the control class showed an increase from 60.75 to 71.30, corresponding to a gain of 10.55 points. This disparity indicates that the use of PhET simulations exerts a greater impact on conceptual understanding than conventional instruction. This effect can be attributed to the core features of PhET simulations, which enable dynamic visualization and direct manipulation of variables, thereby assisting students in comprehending abstract physics concepts—particularly in topics related to motion and force—in a more concrete and meaningful manner.

Moreover, inferential statistical analysis reveals that the independent samples t-test yielded a significance value of $0.000 < 0.05$, indicating a statistically significant difference between the experimental and control groups. Therefore, the alternative hypothesis (H_1) is accepted, confirming that PhET simulation-based learning has a significant effect on students' conceptual understanding. In addition, the normalized gain (N-gain) analysis shows that the experimental class achieved an average score of 0.70 (high category), whereas the control class obtained an average score of 0.35 (medium category). These results further substantiate the superiority of PhET-based instruction over conventional methods in enhancing students' conceptual understanding.

From a theoretical perspective, the observed improvement in conceptual understanding can be explained through the lens of constructivist learning theory, which posits that knowledge is actively constructed through learners' interactions and experiences. In this context, PhET simulations provide an exploratory environment in which students can observe physical phenomena, manipulate variables, and directly examine cause-and-effect relationships. Additionally, these findings are consistent with Mayer's Cognitive Theory of Multimedia Learning, which suggests that the integration of visual and verbal information enhances comprehension. By combining animations, graphical representations, and interactive controls, PhET simulations help reduce cognitive load and facilitate deeper conceptual understanding rather than rote memorization.

In line with this, the present findings corroborate previous studies highlighting the effectiveness of interactive simulations in physics education. Studies by Perkins et al. (2006) and Finkelstein et al. (2006) demonstrate that PhET simulations significantly enhance student engagement and conceptual understanding, and in certain contexts can even substitute traditional laboratory activities. Similarly, Wieman et al. (2010) confirm that simulation-based learning effectively supports students in grasping abstract concepts. However, these findings contrast with those reported by Kurniawan (2019), who found no significant improvement due to insufficient instructional guidance during simulation use. This discrepancy suggests that the effectiveness of PhET simulations depends not only on the technology itself but also on the instructional design and the teacher's role in facilitating learning.

Furthermore, this study contributes significantly to the field of physics education, particularly in advancing technology-enhanced learning innovations. Empirically, the findings provide robust evidence that PhET simulations can substantially improve students' conceptual understanding. Practically, this research offers an effective instructional alternative for teachers in delivering abstract physics content through interactive digital media. Consequently, these findings may serve as a valuable reference for the development of more interactive, contextual, and technology-integrated learning designs aligned with the demands of 21st-century education.

Nevertheless, this study has several limitations, including a relatively small sample size, a narrow focus on a single physics topic, and a limited duration of implementation. These constraints may affect the generalizability of the findings. Therefore, future research is recommended to involve larger and more diverse samples, encompass multiple educational levels, and investigate a wider range of physics topics. Additionally, longitudinal studies are needed to examine the sustainability of students' conceptual understanding following the implementation of PhET simulation-based learning, thereby providing a more comprehensive evaluation of its long-term effectiveness.

CONCLUSION

Based on the findings of this study on the implementation of PhET simulation-based learning in physics education, it can be concluded that the research has successfully achieved its objective. This study aimed to analyze the effect of PhET simulations on students' conceptual understanding, and the results clearly indicate a significant improvement in learning outcomes following the application of the simulation-based approach. The results reveal that students in the experimental group demonstrated a substantially higher improvement in conceptual understanding, as reflected by the increase in the mean score from 61.20 to 83.45 and an N-gain value of 0.70, categorized as high. These findings confirm that PhET simulation-based learning is more effective than conventional instructional methods. Moreover, the analysis indicates that interactive simulations play a crucial role in facilitating students' comprehension of abstract physics concepts through dynamic visualization and active engagement, thereby enhancing the depth and quality of conceptual learning.

Furthermore, this study contributes to the advancement of physics education by providing empirical support for the development of simulation-based instructional models that enhance students' conceptual understanding and learning engagement. The findings also reinforce the relevance of constructivist learning theory and Mayer's Cognitive Theory of Multimedia Learning in classroom practice, offering a pedagogically sound and technology-integrated strategy to improve the effectiveness of physics instruction. In a broader context, these findings offer strategic implications for strengthening physics education at both national and international levels. Nationally, this study supports the integration of digital learning media into classroom practices, thereby contributing to the improvement of teaching quality and educational outcomes. Internationally, the results enrich the global body of knowledge on simulation-based learning and promote the adoption of interactive digital technologies as innovative approaches in science education, fostering further academic discourse and cross-border research collaboration. Nevertheless, this study is subject to certain limitations, including a relatively limited sample size, a focus on a single topic, and a short duration of implementation. Therefore, future research is recommended to involve larger and more diverse samples across different educational levels to enhance the generalizability of the findings. Additionally, subsequent studies may incorporate other relevant variables, such as critical thinking skills, problem-solving abilities, and learning motivation, as well as conduct longitudinal investigations to examine the long-term sustainability of students' conceptual understanding following the use of PhET simulation-based learning.

REFERENCES

Amir, M. I. T., Hertanti, E., & Suwarna, I. P. (2026). Pengaruh PhET Interactive Simultions terhadap Pemahaman Konsep Siswa pada Materi Termodinamika. *Jurnal Pendidikan Matematika Dan Sains*, *14*(1), 121–130.

Chairunisa, T. (2024). Efektivitas Penggunaan Media Pembelajaran PhET dalam Meningkatkan Hasil Belajar Siswa pada Pembelajaran Fisika. *Jurnal Pendidikan Dan Pembelajaran Khatulistiwa (JPPK)*, *1*(01), 115–127.

Ekawati, Y., Haris, A., & Amin, B. D. (2015). Penerapan media simulasi menggunakan phet (physics education and technology) terhadap hasil belajar fisika peserta didik Kelas x sma muhammadiyah limbung. *Jurnal Pendidikan Fisika*, *3*(1), 74–82.

Fadlan, M., Fadillah, N., Liliawati, W., & Sari, I. M. (2024). Pengembangan Instrumen Sound Wave Two Tier (Sowatt) Diagnostic Test: Analisis Rasch Model. *U-Teach: Journal Education of Young Physics Teacher*, *5*(2), 81–90.

Finkelstein, N., Adams, W., Keller, C., Perkins, K., & Wieman, C. (2006). High-tech tools for teaching physics: The physics education technology project. *Journal of Online Learning and Teaching*, *2*(3), 110–121.

Gabel, D. (2003). Enhancing the conceptual understanding of science. *Educational Horizons*, *81*(2), 70–76.

Hamdi, A. S. (2015). *Metode penelitian kuantitatif aplikasi dalam pendidikan*. Deepublish.

Kenny, D. A. (1975). A quasi-experimental approach to assessing treatment effects in the nonequivalent control group design. *Psychological Bulletin*, *82*(3), 345.

Magfirah, L. (2024). Pemanfaatan Simulasi digital untuk memfasilitasi pembelajaran konsep abstrak dalam fisika. *Jurnal Ilmiah IPA Dan Matematika (JIIM)*, *2*(2), 28–33.

Maulida, I. N., Taufik, M., & Kosim, K. (2022). Pengaruh media PhET dalam model discovery learning terhadap pemahaman konsep fisika peserta didik. *Jurnal Ilmiah Profesi Pendidikan*, *7*(3), 1150–1156.

Nasution, N., & Harida, D. D. E. S. (n.d.). *Media Pembelajaran Audio Visual Dalam Pembelajaran Siswa Di Pendidikan Dasar*.

Nurulhidayah, M. R., Lubis, P. H. M., & Ali, M. (2020). Pengaruh model pembelajaran discovery learning menggunakan media simulasi PhET terhadap pemahaman konsep fisika siswa. *Jurnal Pendidikan Fisika FKIP UM Metro*, *8*(1), 95–103.

Perkins, K., Adams, W., Dubson, M., Finkelstein, N., Reid, S., Wieman, C., & LeMaster, R. (2006). PhET: Interactive simulations for teaching and learning physics. *The Physics Teacher*, *44*(1), 18–23.

Purwana, I. G., Saputra, E., Nigsih, S., Bulaka, B., & Sari, R. S. (2025). *Pengaruh Penggunaan Phet Simulasi Terhadap Peningkatan Hasil Belajar Fisika : Upaya Menjawab Tantangan Transformasi Pembelajaran Fisika Era*. *8*(3), 117–130.

Rizaldi, D. R., Jufri, A. W., & Jamaluddin, J. (2020). PhET: Simulasi interaktif dalam proses pembelajaran fisika. *Jurnal Ilmiah Profesi Pendidikan*, *5*(1), 10–14.

Sabaryati, J., Utami, L. S., & Zulkarnain, Z. (2021). Pengembangan Motion Sensor Eksperiment Dalam Problem Based Learning. *ORBITA: Jurnal Kajian, Inovasi Dan Aplikasi Pendidikan Fisika*, *7*(1), 225. https://doi.org/10.31764/orbita.v7i1.4791

Saripudin, S., & Robbani, M. D. F. (2024). Integrasi teknologi dalam pendidikan. *EDUTECH*, *23*(3), 336–346.

Sasmita, P. R., Hartoyo, Z., & Sutrisna, N. (2023). Pengaruh media simulasi interaktif PhET terhadap pemahaman konsep fisika siswa. *Jurnal Ilmiah Wahana Pendidikan*, *9*(3), 109–116.

Susanti, R. (2005). Sampling dalam penelitian pendidikan. *Jurnal Teknodik*, 187–208.

Utami, M. F. N. M., Mastuang, M., & Haryandi, S. (2023). Is 21st Century Learning Need STEM Approach built into Physics Comics? *Jurnal Ilmiah Pendidikan Fisika*, *7*(2), 319. https://doi.org/10.20527/jipf.v7i2.6780

Utami, V., Viyanti, & Permadi, D. (2025). Jurnal Materi dan Pembelajaran Fisika Enhancing Students ' Critical Thinking Integrated Problem-Based Learning Model Skills : A. *JMPF: Jurnal Materi Dan Pembelajaran Fisika*, *15*(1), 17–24.

Wieman, C. E., Adams, W. K., Loeblein, P., & Perkins, K. K. (2010). Teaching physics using PhET simulations. *The Physics Teacher*, *48*(4), 225–227.

Wieman, C. E., Adams, W. K., & Perkins, K. K. (2008). PhET: Simulations that enhance learning. *Science*, *322*(5902), 682–683.

Zulkarnain, Z., Islahudin, I., Isnaini, M., Utami, L. S., Anwar, K., & Darmayanti, N. W. S. (2023). Project 2-D Motion Simulation Based on Matlab Graphical User Interface in Physics Learning. *Radiasi : Jurnal Berkala Pendidikan Fisika*, *16*(1), 9–16. https://doi.org/10.37729/radiasi.v16i1.2149

Zulkarnain, Z., Utami, L. S., Sabaryati, J., Islahudin, I., Subhan, S., & Arisandi, D. (2024). Design of virtual laboratory media based on HTML 5 Canvas and graphical user interface in physics learning. *Journal of Instructional and Development Researches*, *4*(6), 477–485. https://doi.org/10.53621/jider.v4i6.405