



The Effect of Problem Based Learning Model Assisted by PhET Simulation on Understanding Physics Concepts

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Abstract

This study investigates the impact of the Problem-Based Learning (PBL) model assisted by PhET simulations on students' understanding of physics concepts. Recognizing the persistent challenge students face in grasping abstract physics concepts, this research integrates innovative teaching methods to enhance conceptual comprehension. The study employs a quasi-experimental design with a non-equivalent control group format, involving eleventh-grade science students from SMAN 1 Bayan, North Lombok. The experimental group, taught using the PBL model enhanced with PhET simulations, demonstrated significant improvements in posttest scores compared to the control group, which followed traditional lecture-based instruction. Data analysis, including validity, reliability, discrimination power, and difficulty level tests, confirmed the robustness of the concept understanding instrument. ANOVA results indicated a substantial effect of the intervention, with the experimental group showing a higher mean score and lower variability in performance. The findings reveal that the PBL model, supported by interactive PhET simulations, effectively enhances students' conceptual understanding in physics. This study contributes to the broader discourse on educational innovations by providing empirical evidence of the benefits of combining PBL with technological tools in physics education. It underscores the need for student-centered learning approaches that foster critical thinking and active participation. Future research should explore the scalability of this method across diverse educational contexts and further refine the integration of digital simulations to cover a broader range of physics topics.

Keywords: Problem-based learning; PhET simulation; Conceptual understanding; Physics Education; Technological tools.

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INTRODUCTION

The comprehension of concepts is crucial as they form the foundation for higher mental processes involved in formulating principles and generalizations (Mauke et al., 2013). However, many students struggle to grasp the concepts taught in physics education. This difficulty often stems from misconceptions and a poor understanding of the subject matter (Yusuf et al., 2022). Instead of comprehending material, students tend to memorize it, which leads to a quicker forgetfulness of the learned content. Enhancing conceptual understanding is essential for students to cultivate their critical thinking abilities. Therefore, educators must focus on developing students' thinking skills to enable them to solve problems in physics learning effectively.

Physics plays a pivotal role in advancing scientific knowledge within the educational sphere by encouraging students to think actively and creatively. It is also crucial for fostering personal character traits such as cognitive, affective, and psychomotor skills, all based on a profound understanding of knowledge that aids in solving natural phenomena (Salveti et al., 2023). The physics education process should align with the Indonesian National Education Standards, promoting a more

active student involvement in learning. Given that many physics concepts are abstract, they can be challenging for students to understand. Thus, it is necessary to utilize constructive, innovative, and student-centered teaching methods and media to clarify these abstract concepts and make them more accessible to students.

Based on observations conducted at SMAN 1 Bayan in North Lombok, it was found that student engagement in physics learning activities in the classroom is lacking. Teachers predominantly continue to deliver lessons using traditional methods, predominantly lecturing and writing on the chalkboard from the beginning to the end of the class, which indicates a lack of student-centered teaching approaches. This teaching model results in students merely listening and copying material presented by the teacher, which hinders their ability to effectively understand physics concepts. Furthermore, the use of instructional media that could simplify explanations and aid student comprehension is underutilized. Additionally, practical laboratory activities, both in actual and virtual labs, are seldom conducted.

Most students face challenges in understanding physics concepts, as highlighted in various studies. These difficulties are not solely due to a lack of mathematical knowledge (Planinić et al., 2013), and traditional problem-solving methods may not effectively enhance conceptual understanding (Eun-Sook & Pak, 2002). Physics students tend to rely heavily on formulas, while non-physics students often use common-sense strategies, indicating a gap in physics conceptual understanding (Sušac et al., 2018). Concept inventories have revealed significant gaps in students' understanding of physics, prompting a shift towards more effective teaching methods like active learning (Cetnar, 2023). Teaching strategies such as reciprocal teaching have been shown to positively impact students' academic self-concept in physics (Mafarja et al., 2023). Additionally, the use of online homework systems can enhance students' learning of physics concepts (Cheng et al., 2004). However, despite repeated explanations, students still struggle to grasp basic physics concepts (Su, 2010), leading to challenges in retention and self-efficacy (Bada & Jita, 2023). It is crucial for physics teachers to identify and address students' misunderstandings through tailored teaching methods (Tao et al., 2018). Overall, addressing students' conceptual difficulties in physics requires a multifaceted approach that combines innovative teaching methods, active learning strategies, and tailored interventions to bridge the gap between theoretical knowledge and practical understanding.

Educators can innovate by implementing teaching models that actively engage students in learning and center on student participation (Grøndahl-Glavind et al., 2023). Learning activities should position students as principal agents, directly involved in the educational process. According to Aliyu et al. (2023), one pedagogical approach that promotes active student involvement and is particularly effective in enhancing critical thinking skills is Problem-Based Learning (PBL). The PBL model utilizes real-world issues as a foundation for students to engage in problem-solving, thereby acquiring knowledge and understanding concepts related to the studied material (Albar & Southcott, 2021). The challenges presented in the PBL model encourage students to collaborate within groups, exchanging ideas and seeking solutions collectively (Suhirman et al., 2021).

Physics, inherently theoretical, can be challenging for students to grasp and often requires validation through experiments (Zafeiropoulou et al., 2021). These experiments are crucial for facilitating a deeper understanding of the subject matter. However, due to the limited availability of experimental apparatus, students rarely engage in hands-on experiments. A solution to this limitation is the use of virtual laboratories, which allow students to observe phenomena that are otherwise difficult to demonstrate (Ahmed & Hasegawa, 2021; Bedetti et al., 2018; Chang et al., 2022). One widely used virtual laboratory application is the PhET (Physics Education Technology) simulation, which hosts numerous scientific experiments aiding in the comprehension of abstract scientific concepts (Chinaka, 2021; Correia et al., 2019; Ndiokubwayo et al., 2020; Verawati et al., 2022).

PhET is a virtual laboratory platform accessible both online and offline via computers, smartphones, and similar devices, overcoming the limitations of physical laboratory equipment for conducting experiments (El-Kharki et al., 2021). The PhET application is designed to offer various problem-solving activities that can be integrated during learning sessions. By incorporating PhET simulations into the Problem-Based Learning model, it is anticipated that students will better understand the concepts of physics.

Research Objectives and Questions

Given the background concerning the low level of students' understanding of physics concepts, the researcher is motivated to conduct a study exploring the effects of the Problem-Based Learning (PBL) model assisted by PhET simulations on students' conceptual understanding in physics. Specifically, the research question posed is as follows:

- What is the effect of the Problem-Based Learning model assisted by PhET simulations on students' understanding of physics concepts?

Novelty of the Study

This study introduces a novel approach to physics education by integrating the Problem-Based Learning (PBL) model with PhET simulations, a method not extensively explored in previous research within the context of Indonesian educational settings, especially in physics. These simulations offer dynamic, interactive environments that allow students to visualize and manipulate physical phenomena, potentially bridging the gap between theoretical concepts and practical understanding. This integration aims to transform the traditional passive learning atmosphere into an engaging, student-centered experience.

The research uniquely addresses the persistent issue of low conceptual understanding in physics by leveraging technology to facilitate active learning. Despite the known benefits of active learning strategies in improving physics education outcomes, the specific combination of PBL and PhET simulations represents an innovative fusion of pedagogy and technology. By employing PhET simulations within the PBL framework, this study explores how virtual experiments can supplement the problem-solving activities, providing immediate feedback and allowing students to experiment with concepts in a risk-free environment. This approach is anticipated to enhance students' engagement and retention of complex physics concepts more effectively than traditional methods.

Furthermore, the study contributes to the field by focusing on the effects of this integrated model on students' understanding in a real-world educational setting, providing empirical data from SMAN 1 Bayan in North Lombok. This focus on a local context with specific educational challenges adds significant value to the global discourse on physics education, offering insights that could inform future educational practices and policy decisions. By examining the impact of innovative teaching strategies on student outcomes, this research could serve as a model for other regions facing similar challenges in science education, advocating for broader adoption of technologically enhanced, student-centered learning paradigms.

METHODS

This study adopted a quasi-experimental research design using a non-equivalent control group format, as outlined by Creswell and Creswell (2018). The purpose of employing this design was to compare the outcomes of two different teaching approaches on students' understanding of physics concepts. The experimental group received instruction through a problem-based learning (PBL) model enhanced with PhET simulations, designed to engage students actively and mimic real-world problem-solving scenarios in physics. The control group, on the other hand, was taught using traditional lecture-based methods, which provided a comparative baseline to evaluate the effectiveness of the innovative PBL approach. Both groups were subjected to pretests and posttests to assess their initial knowledge states and the subsequent impact of the instructional methods.

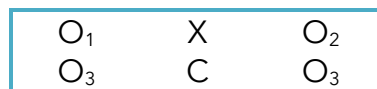


Figure 1. Research design

The research design was meticulously planned to ensure robustness in measuring the effect of the intervention. Figure 1 in the study illustrates the design structure, where O₁ and O₂ represent the pretest and posttest for the experimental group, and O₃ and O₄ represent the pretest and posttest for the control group. This setup allowed for the assessment of both the initial equivalence of the groups and the differential impact of the intervention. The use of this design was crucial for establishing causal relationships and understanding the specific contributions of the PhET-assisted PBL model in enhancing students' physics concept comprehension.

The participants of this study were drawn from SMAN 1 Bayan, consisting of students from two eleventh grade science classes during the academic year 2022/2023. Class XI MIPA 1, consisting of 30 students, was selected as the experimental group, and class XI MIPA 2, with 28 students, served as the control group. The selection of these specific classes was based on purposive sampling, chosen for their homogeneity in terms of academic performance and demographics, which minimized potential confounding variables. This sample size was deemed adequate for statistical analysis, allowing for a comprehensive evaluation of the educational interventions.

Ethical considerations were paramount in this research, especially given the involvement of minor students as participants. Prior to the commencement of the study, informed consent was obtained from both the students and their guardians,

ensuring they were fully aware of the research's nature, purpose, and procedures. Confidentiality and anonymity of the participants were strictly maintained throughout the study. The educational interventions were designed to align with the standard curriculum to ensure that no student was disadvantaged by participating in the study. Ethical approval was also secured from the institutional review board of SMAN 1 Bayan, adhering to ethical guidelines for research involving human subjects.

The research procedure began with the administration of a pretest to both the experimental and control groups to establish a baseline measure of their understanding of physics concepts. Following the pretest, the experimental group engaged in a problem-based learning framework that integrated PhET simulations into their learning activities. This approach emphasized student interaction with virtual experiments to explore physics concepts dynamically, fostering a deeper understanding through inquiry and application. The control group, meanwhile, continued with traditional instruction, focused primarily on lecture and textbook-based learning, without the inclusion of interactive simulations. Figure 2 displays a recording of the PhET simulation utilized during the instructional period on fluid mechanics material.

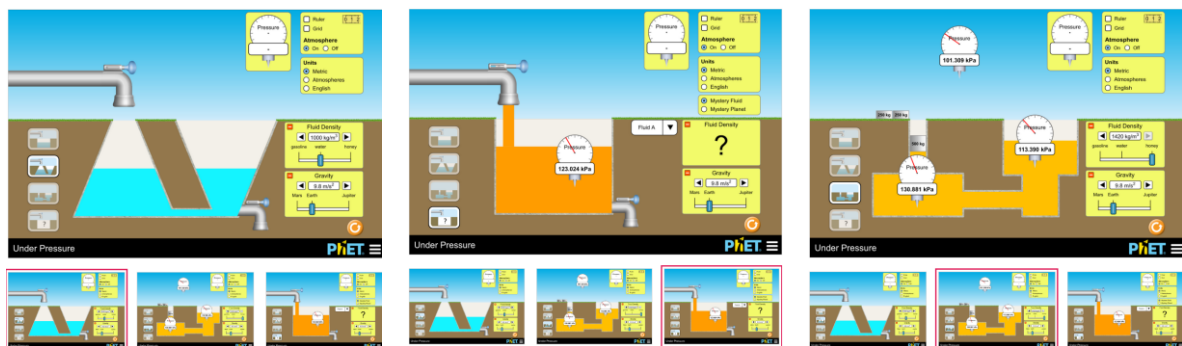


Figure 2. PhET simulation on fluid mechanics material

At the conclusion of the instructional period, a posttest was administered to both groups. This test was identical to the pretest to ensure comparability of results. The intervention lasted for a total of eight weeks, during which the progress and engagement of the students were monitored. The use of PhET simulations in the experimental group was designed to provide insights into the practical application of physics concepts, aiming to enhance conceptual understanding significantly compared to the conventional teaching methods employed in the control group.

The primary instrument used in this study was a standardized multiple-choice test, designed to assess students' understanding of key physics concepts. The test comprised items that were carefully selected and validated for content accuracy, relevance, and alignment with the learning objectives of the physics curriculum. Each test item underwent a rigorous validation process involving subject matter experts to ensure reliability and appropriateness for the target student population. The same test was used for both the pretest and posttest to measure learning gains accurately. Concept understanding test items are designed using Bloom's Taxonomy (Krathwohl, 2002). This taxonomy identifies six cognitive levels that range from simple recall to complex evaluative thinking.

Data collected from the tests were analyzed using SPSS version 21. The initial step in the analysis involved conducting prerequisite checks, including tests for normality and homogeneity of variance, to validate the assumptions of the subsequent analysis of variance (ANOVA). The hypothesis testing was carried out using an ANOVA, aimed at comparing the mean scores of the experimental and control groups on the posttest. This analysis helped determine the effectiveness of the problem-based learning model enhanced by PhET simulations in improving students' understanding of physics concepts compared to traditional teaching methods. The statistical significance and effect size were reported to provide a clear understanding of the impact of the educational interventions.

RESULTS AND DISCUSSION

A study has been conducted to explore the effect of the Problem-Based Learning (PBL) model assisted by PhET simulations on students' understanding of physics concepts. The research findings detail various outcomes from the instrument trials, including descriptions of discoveries and the results of hypothesis testing. The instrument testing encompasses several aspects: validity, reliability, discrimination power, and difficulty level of the test instruments. The validity test of the instruments was conducted to determine whether the test instruments used were valid. Before being utilized in the study, the concept understanding instruments were first subjected to validity testing. The results of the validity tests for the concept understanding test instruments are presented in Table 1.

Table 1. Instrument validity results

Instrument	Number of items	Valid	Invalid
Concept understanding test	30	25	5

Table 1 provides the validity results for the instrument used in the study, specifically focusing on the concept understanding test. Out of the 30 items included in the test, 25 items were found to be valid, meaning they effectively measure what they are intended to assess in terms of students' understanding of physics concepts. However, 5 items were deemed invalid, indicating that these particular questions may not accurately reflect or measure the intended concepts. These findings are crucial for refining the test to ensure that all items contribute meaningfully to assessing students' conceptual understanding accurately.

Reliability testing was conducted to determine whether the concept understanding instrument used in the study possesses sufficient reliability (confidence level) to serve as a data collection tool. In this research, the reliability of the instrument was assessed using Cronbach's Alpha, and the analysis was facilitated by the SPSS 21 software program. The results of the reliability analysis are presented in Table 2.

Table 2. Instrument reliability test results

Variable	Cronbach's-Alpa	r_{tabel}	Alpa > 0,381
Concept understanding	0,821	0,361	Reliable

Table 2 outlines the results from the reliability test of the instrument used to assess concept understanding. The Cronbach's Alpha value obtained was 0.821, which significantly exceeds the threshold value (r_{tabel}) of 0.361, indicating that the

instrument is reliable. Since the Alpha value is greater than 0.381, it confirms that the instrument has a high level of internal consistency and can be trusted to provide accurate and consistent measurements of students' understanding of physics concepts, thereby validating its use as a dependable tool for data collection in the study. Furthermore, the results of the different power test for understanding the concept are presented in Table 3.

Table 3. The results of the power test differ regarding understanding the concept

Item category	Number of items	Items
Accepted	25	1,2,3,4,5,6,8,10,11,12,13,14,15,19,20,21,22,23,24,25,26,27,28,29,30
Corrected	0	-
Rejected	5	7,9,17,18,16

Table 3 presents the outcomes of the discrimination power test concerning the concept understanding test items. Out of the total items evaluated, 25 were accepted, indicating that they effectively differentiate between students who have mastered the physics concepts and those who have not. These accepted items include numbers 1 through 6, 8, 10 through 15, 19 through 25, 26 through 30. Conversely, 5 items were rejected (items 7, 9, 16, 17, 18) because they failed to adequately discriminate between different levels of understanding among the students. No items required corrections, as indicated by the zero count in the 'Corrected' category, underscoring the robustness of the majority of the test items in assessing conceptual understanding accurately. Furthermore, The analysis results of the difficulty level of the concept understanding instrument are presented in Table 4.

Table 4. Results of the difficulty level test of the concept understanding instrument

Item category	Number of items	Items
Difficult	9	5,7,13,14,18,22,26,27,30
Medium	16	8,9,10,11,12,15,17,19,20,21,23,24,25,28,29
Easy	5	1,2,3,4,6,16

Table 4 displays the results from the difficulty level analysis of the concept understanding instrument used in the study. The items were categorized based on their level of difficulty: 9 items (numbers 5, 7, 13, 14, 18, 22, 26, 27, 30) were classified as difficult, indicating that they pose a higher challenge to students and require a deeper understanding of physics concepts. A majority of 16 items (numbers 8, 9, 10, 11, 12, 15, 17, 19, 20, 21, 23, 24, 25, 28, 29) were categorized as medium in difficulty, suggesting a balanced level of challenge suitable for testing average comprehension. Additionally, 5 items (numbers 1, 2, 3, 4, 6, 16) were deemed easy, implying they are likely to be correctly answered by most students, thus serving as confidence-building questions within the test framework. This categorization helps in ensuring that the test assesses a range of abilities, from basic to advanced understanding of the subject matter.

The research findings related to students' concept understanding in both the experimental and control groups (Table 5) provides a detailed comparison of students' conceptual understanding in both the control and experimental groups, measured before and after the intervention using pretest and posttest scores.

Initially, both groups started with a similar number of valid responses (28 in the control and 30 in the experimental groups). The mean pretest scores were relatively close, with the control group scoring 28.71 and the experimental group scoring 27.60. This initial similarity suggests that both groups were comparable at the start of the study. Standard errors and deviations are within expected ranges, indicating consistency in scoring within the groups.

Table 5. Pretest-posttest scores of students' conceptual understanding in the experimental and control groups

Measured Aspects	Pretest		Posttest	
	Control	Experimental	Control	Experimental
Valid	28	30	28	30
Mean	28.71	27.60	51.78	62.13
Std. Error of Mean	1.44	1.31	2.16	1.48
Std. Deviation	7.63	7.15	11.45	8.10
Coefficient of variation	0.27	0.26	0.22	0.13
Minimum	12.00	16.00	24.00	44.00
Maximum	40.00	40.00	72.00	78.00

The posttest results, however, highlight a significant difference in outcomes between the two groups. The experimental group, which utilized the Problem-Based Learning model assisted by PhET simulations, showed a notable increase in the mean score from 27.60 to 62.13, surpassing the control group's increase from 28.71 to 51.78. This suggests a more effective conceptual understanding development in the experimental group. The standard deviation and error of mean in the posttest scores also remained consistent, affirming the reliability of the test scores. Furthermore, the coefficient of variation decreased significantly in the experimental group (from 0.26 to 0.13), indicating less variability in performance and a stronger grasp of physics concepts among these students. The range between the minimum and maximum scores in both groups widened, with the experimental group achieving a higher maximum score, further demonstrating the effectiveness of the intervention.

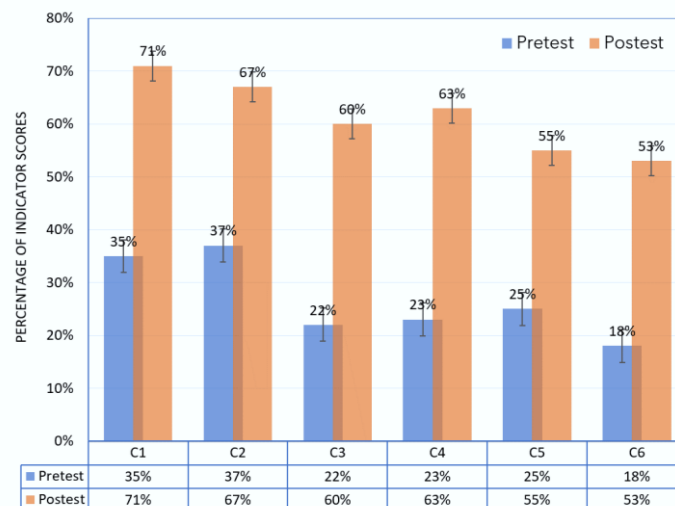


Figure 3. Graph of the percentage of achievement for each indicator of concept understanding in the experimental group

The scores for each indicator of concept understanding (in the pretest and posttest) for the experimental and control groups are presented in Figure 3 and Figure 4, respectively. Based on the results shown in Figure 3, it was found that all concept understanding indicators from C1 to C2 increased after the intervention. This indicates that the Problem-Based Learning process assisted by PhET simulations improved the students' concept understanding in the experimental group. The scores for each concept understanding indicator for the control group are presented in Figure 4.

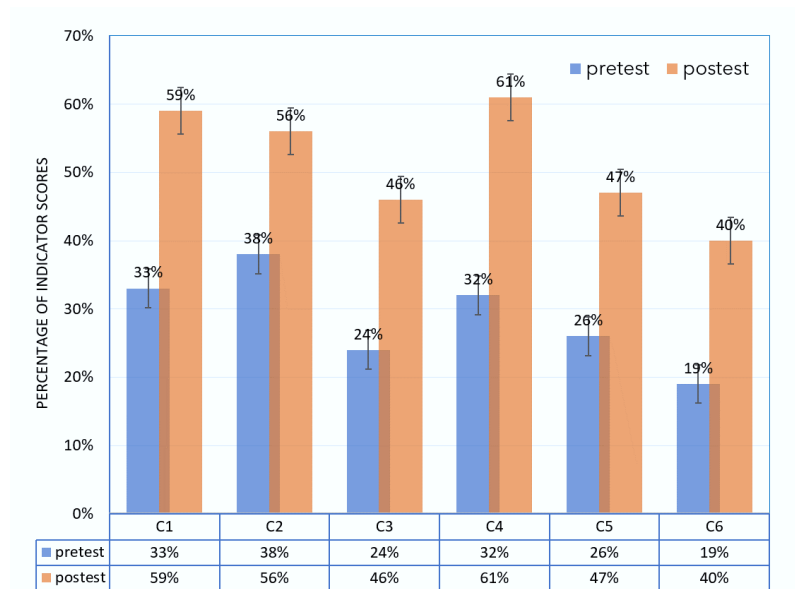


Figure 4. Graph of the percentage of achievement for each indicator of concept understanding in the control group

Based on Figure 4, it is observed that all concept understanding indicators showed improvement in the control group, although the increases were not as substantial as those in the experimental group. Subsequently, a hypothesis test was conducted to determine the differences in concept understanding between the experimental and control groups. This is aimed at examining the effect of the Problem-Based Learning model assisted by PhET simulations on students' understanding of physics concepts. Prerequisite tests were performed before the hypothesis testing to check if the data were normally distributed and homogeneous. The results indicated that the data were both normally distributed and homogeneous, with both tests showing a significance greater than 0.05. The hypothesis testing in this study utilized ANOVA, with the results summarized in Table 6.

Table 6. ANOVA test results from posttest data in the experimental and control groups

Cases	Sum of squares	df	Mean square	F	p	VS-MPR*	η^2
Posttest	1550.77	1	1550.72	15.96	< .001	224.95	0.22
Residuals	5442.18	56	97.18				

*VS-MPR = Vovk-Sellke Maximum p -Ratio

The results from the ANOVA test, as detailed in Table 6, demonstrate significant differences in the posttest scores between the experimental and control

groups, which were analyzed to assess the effectiveness of the Problem-Based Learning model assisted by PhET simulations. The analysis revealed a substantial sum of squares between the groups (1550.77) with one degree of freedom, resulting in a mean square of 1550.72. The computed F-value of 15.96, along with a p-value less than 0.001, indicates a statistically significant difference in concept understanding between the groups. This suggests that the intervention using the PBL model supported by PhET simulations had a pronounced positive effect on the students' understanding of physics concepts.

Further statistical analysis using the Vovk-Sellke Maximum p-Ratio (VS-MPR) resulted in a maximum p-ratio of 224.95, underscoring the strength and significance of the test result. Additionally, the eta squared (η^2) value of 0.22 suggests that approximately 22% of the variance in concept understanding scores across the groups can be attributed to the intervention. This moderate effect size further validates the educational impact of the Problem-Based Learning approach enhanced by PhET simulations, confirming its effectiveness in improving conceptual understanding among physics students.

The integration of the Problem-Based Learning (PBL) model supported by PhET simulations has significantly enhanced students' understanding of physics concepts, as evidenced by the findings from our study. This improvement aligns with existing research suggesting that PBL enhances student attitudes and participation more effectively than traditional lecture-based methods (Kim et al., 2016). The active engagement required in PBL encourages deeper learning and greater satisfaction among students, which likely contributed to the positive outcomes observed in our experimental group. This method facilitates an educational environment where students are not merely passive recipients of information but active participants in constructing their understanding.

PhET simulations play a critical role in this integrated learning approach by providing interactive and dynamic tools for exploring complex physics concepts. Studies have shown that these simulations aid in the intuitive development of mental models, particularly in challenging subjects like quantum mechanics (McKagan et al., 2008; Saudelli et al., 2021). In our study, the use of PhET simulations allowed students to visualize and manipulate physical phenomena in real-time, which helped in cementing their understanding and retaining difficult concepts more effectively.

The effectiveness of PBL in enhancing problem-solving skills has been well-documented, with research indicating significant improvements in students' ability to apply physics concepts to solve practical problems (Yanto et al., 2021). This enhancement of problem-solving capabilities is crucial in physics education, where the application of theoretical knowledge to solve real-world challenges is a key learning outcome. Our findings suggest that the PBL model, especially when combined with PhET simulations, provides a robust framework for developing these essential skills. Moreover, the combination of PBL and PhET simulations has proven effective in increasing student interest and engagement in learning physics (Ismalia et al., 2022). By making learning more interactive and less monotonous, these tools motivate students to explore and inquire, leading to improved cognitive engagement and thinking skills. This increased engagement was evident in our

study, where students in the experimental group demonstrated higher interest and participation levels compared to the control group.

Incorporating PhET simulations into PBL not only supports the learning of abstract physics concepts but also enhances students' digital literacy skills. As students navigate through various simulations, they develop a better understanding of how to use technology to facilitate their learning, which is an essential skill in the modern educational landscape. This aspect of the learning process prepares students not only for advanced studies in scientific fields but also equips them with the technological proficiency needed in many modern careers. Furthermore, the use of PBL supported by PhET simulations has shown to improve students' cooperative learning abilities (Fan et al., 2018). Working together in groups to solve problems presented in simulations helps students learn to communicate effectively, share knowledge, and support each other's learning processes. This cooperative aspect of PBL fosters a sense of community and collective responsibility among learners, enhancing the overall educational experience.

Studies have also highlighted the scalability and accessibility of PhET simulations, which are freely available online, making them an excellent resource for educators across various settings (Perkins et al., 2008). This accessibility ensures that innovative teaching methods can be implemented without significant resource constraints, allowing for broader adoption in diverse educational contexts. The findings from our study suggest that integrating PBL with PhET simulations similarly impacts various aspects of student learning, contributing to a more rounded educational experience.

The results of the current study are in line with previous research where PhET simulations can challenge, improve, correct, and strengthen conceptual understanding through self-driven exploration, contributing to enhanced learning outcomes (Clark & Chamberlain, 2014). Additionally, the use of PhET simulations in learning environments has been associated with improved conceptual understanding, insight into the nature of science, awareness of historical experiments, and increased motivation levels among students (Banda & Nzabahimana, 2022; , Susilawati et al., 2022 ; , Doyan et al., 2021). Furthermore, the incorporation of PhET simulations in teaching has been found to not only enhance students' understanding and intuition but also promote independent learning (Verawati et al., 2022). These simulations have been effective in improving students' learning outcomes, motivation, problem-solving skills, and mastery of concepts across various subjects (Khairiyah et al., 2022; , Efendi & Sartika, 2021; , Azzubairiyah et al., 2022). The interactive nature of PhET simulations has been particularly beneficial in attracting students' interest and engagement in both hybrid and fully online learning settings (Juwairiah et al., 2022).

Despite the proven benefits of integrating PBL with PhET simulations, challenges such as ensuring consistent access to technology and training educators to effectively implement these tools must be addressed. However, the potential for significant improvements in student learning outcomes justifies the effort required to overcome these challenges. In conclusion, our study confirms that the integration of the Problem-Based Learning model with PhET simulations provides a powerful educational framework for enhancing conceptual understanding, problem-solving skills, and student engagement in physics education. This model not only supports

academic achievement but also fosters essential skills such as critical thinking, collaboration, and digital literacy, making it a valuable addition to contemporary educational practices in physics.

CONCLUSION

The study conducted on the integration of the Problem-Based Learning (PBL) model assisted by PhET simulations has significantly enhanced students' understanding of physics concepts, substantiating the potential of this innovative educational approach. The findings confirm that the PBL model, especially when supplemented with interactive PhET simulations, not only facilitates a deeper understanding of complex physics concepts but also actively engages students in the learning process. This engagement is reflected in the improved posttest scores of the experimental group compared to the control group, illustrating the effective application of theoretical knowledge through practical, problem-solving activities that are central to PBL. Additionally, the integration of technology in the form of PhET simulations has proved instrumental in bridging the gap between abstract theoretical concepts and tangible understanding, making learning more accessible and enjoyable for students.

Moreover, the successful implementation of this teaching strategy within the context of Indonesian educational standards, particularly at SMAN 1 Bayan in North Lombok, highlights its applicability and scalability in diverse educational settings. This study not only contributes to the existing body of knowledge by demonstrating the effectiveness of combining PBL with PhET simulations but also sets a precedent for future educational practices. It underscores the importance of adopting innovative, student-centered teaching methods that can significantly enhance conceptual understanding and student engagement. As such, this approach is recommended for broader adoption to address the ongoing challenges in physics education, fostering not only improved academic performance but also critical thinking, problem-solving skills, and a genuine interest in scientific exploration.

RECOMMENDATION

For future directions in physics education, it is recommended that educators and institutions continue to embrace and expand the use of integrated teaching approaches like Problem-Based Learning (PBL) combined with PhET simulations. This approach should be applied not only to enhance conceptual understanding but also to foster critical thinking and problem-solving skills among students. Additionally, further research should investigate the scalability and effectiveness of this method across different educational levels and settings to assess its broader impact. Efforts should also focus on incorporating a wider range of interactive simulations that cover various physics topics, ensuring that these tools are aligned with the curriculum and accessible to all students. Furthermore, teacher training programs should emphasize the development of skills needed to effectively implement these innovative teaching methods, enabling educators to facilitate more dynamic and engaging learning environments. This holistic approach will likely contribute to a more robust and engaging physics education, preparing students to tackle real-world challenges with confidence and competence.

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REFERENCES

- Ahmed, M. E., & Hasegawa, S. (2021). Development of Online Virtual Laboratory Platform for Supporting Real Laboratory Experiments in Multi Domains. *Education Sciences*, 11(9), 548. <https://doi.org/10.3390/educsci11090548>
- Albar, S. B., & Southcott, J. E. (2021). Problem and project-based learning through an investigation lesson: Significant gains in creative thinking behavior within the Australian foundation (preparatory) classroom. *Thinking Skills and Creativity*, 41, 100853. <https://doi.org/10.1016/j.tsc.2021.100853>
- Aliyu, H., Ebikabowei, M., & Kola, A. J. (2023). Problem-Based Learning in Remote Learning Scenario Utilizing Climate Change Virtual Reality Video in Mobile Application to Train Critical Thinking. *International Journal of Essential Competencies in Education*, 2(2), 144-159. <https://doi.org/10.36312/ijece.v2i2.1612>
- Azzubairiyah, N., Erman, E., & Susiyawati, E. (2022). Examining student responses of phet simulations after virtual laboratory practices. *Jurnal Pijar MIPA*, 17(4), 517-519. <https://doi.org/10.29303/jpm.v17i4.3624>
- Bada, A., & Jita, L. (2023). Effect of brain-based teaching strategy on students' retention and self-efficacy in heat energy. *Journal of Technology and Science Education*, 13(1), 276. <https://doi.org/10.3926/jotse.1629>
- Banda, H., & Nzabahimana, J. (2022). The impact of physics education technology (phet) interactive simulation-based learning on motivation and academic achievement among malawian physics students. *Journal of Science Education and Technology*, 32(1), 127-141. <https://doi.org/10.1007/s10956-022-10010-3>
- Bedetti, B., Bertolaccini, L., Patrini, D., Schmidt, J., & Scarci, M. (2018). Virtual simulation and learning new skills in video-assisted thoracic surgery. *Video-Assisted Thoracic Surgery*, 3, 35-35. <https://doi.org/10.21037/vats.2018.08.03>
- Cetnar, A. (2023). Introduction to concept inventories for medical physics education. *Journal of Applied Clinical Medical Physics*, 24(10). <https://doi.org/10.1002/acm2.14130>
- Chang, Y., Kao, J.-Y., & Wang, Y.-Y. (2022). Influences of virtual reality on design creativity and design thinking. *Thinking Skills and Creativity*, 46, 101127. <https://doi.org/10.1016/j.tsc.2022.101127>
- Cheng, K., Thacker, B., Cardenas, R., & Crouch, C. (2004). Using an online homework system enhances students' learning of physics concepts in an introductory physics course. *American Journal of Physics*, 72(11), 1447-1453. <https://doi.org/10.1119/1.1768555>

- Chinaka, T. W. (2021). The Effect of PhET Simulation vs. Phenomenon-based Experiential Learning on Students' Integration of Motion Along Two Independent Axes in Projectile Motion. *African Journal of Research in Mathematics, Science and Technology Education*, 25(2), 185-196. <https://doi.org/10.1080/18117295.2021.1969739>
- Clark, T., & Chamberlain, J. (2014). Use of a phet interactive simulation in general chemistry laboratory: models of the hydrogen atom. *Journal of Chemical Education*, 91(8), 1198-1202. <https://doi.org/10.1021/ed400454p>
- Correia, A.-P., Koehler, N., Thompson, A., & Phye, G. (2019). The application of PhET simulation to teach gas behavior at the submicroscopic level: Secondary school students' perceptions. *Research in Science & Technological Education*, 37(2), 193-217. <https://doi.org/10.1080/02635143.2018.1487834>
- Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th edition). New York: SAGE Publications, Inc.
- Doyan, A., Susilawati, S., Makhrus, M., & Zamrizal, W. (2021). *Development of Modern Physics Learning Devices Using Inquiry Learning Model Assisted with Virtual Media to Improve Student Cognitive Learning Result*. 5th Asian Education Symposium 2020 (AES 2020), Bandung, Indonesia. <https://doi.org/10.2991/assehr.k.210715.047>
- Efendi, N., & Sartika, S. (2021). The effect of distance learning practicum based on phet interactive simulations on science process skills of secondary school students. *Jurnal Pendidikan Sains*, 9(1), 91. <https://doi.org/10.26714/jps.9.1.2021.91-96>
- El-Kharki, K., Berrada, K., & Burgos, D. (2021). Design and Implementation of a Virtual Laboratory for Physics Subjects in Moroccan Universities. *Sustainability*, 13(7), 3711. <https://doi.org/10.3390/su13073711>
- Eun-Sook, K., & Pak, S. (2002). Students do not overcome conceptual difficulties after solving 1000 traditional problems. *American Journal of Physics*, 70(7), 759-765. <https://doi.org/10.1119/1.1484151>
- Fan, X., Geelan, D., & Gillies, R. (2018). Evaluating a novel instructional sequence for conceptual change in physics using interactive simulations. *Education Sciences*, 8(1), 29. <https://doi.org/10.3390/educsci8010029>
- Grøndahl-Glavind, J., Montes De Oca, L., Pechmann, P., Brauner Sejersen, D., & Iskov, T. (2023). Student-centred learning and teaching: a systematic mapping review of empirical research. *Journal of Further and Higher Education*, 47(9), 1247-1261. <https://doi.org/10.1080/0309877X.2023.2241391>
- Ismalia, I., M, K., & Wahyuni, P. (2022). Investigating the use of phet simulation as a substitute for practical tools in understanding the concept of static electricity. *International Journal of Education and Teaching Zone*, 1(1), 20-25. <https://doi.org/10.57092/ijetz.v1i1.7>
- Juwairiah, J., Riana, M., & Windiani, W. (2022). Digitization of laboratory equipment using phet simulation media in applied chemistry practicum. *International Journal of Trends in Mathematics Education Research*, 5(2), 169-173. <https://doi.org/10.33122/ijtmr.v5i2.131>
- Khairiyah, U., Faizah, S., & Dewi, L. (2022). Mastery level of basic concept of science course using stem-pbl based phet simulation application. *Education and*

- Human Development Journal*, 7(03), 57-63.
<https://doi.org/10.33086/ehdj.v7i03.3607>
- Kim, J., Park, J., & Shin, S. (2016). Effectiveness of simulation-based nursing education depending on fidelity: a meta-analysis. *BMC Medical Education*, 16(1). <https://doi.org/10.1186/s12909-016-0672-7>
- Krathwohl, D. R. (2002). A Revision of Bloom's Taxonomy: An Overview. *Theory Into Practice*, 41(4), 212-218. https://doi.org/10.1207/s15430421tip4104_2
- Mafarja, N., Zulnaidi, H., & Fadzil, H. (2023). Effect of reciprocal teaching strategy on physics student's academic self-concept. *International Journal of Evaluation and Research in Education*, 12(2), 1023. <https://doi.org/10.11591/ijere.v12i2.23628>
- Mauke, M., Sadia, I. W., & Suastra, I. W. 2013. Pengaruh Model Contextual Teaching and Learning Terhadap Pemahaman Konsep dan Kemampuan Pemecahan Masalah dalam Pembelajaran IPA-Fisika di MTs Negeri Negara. *Jurnal Pendidikan dan Pembelajaran IPA Indonesia* 3(2), 23-30. https://ejournal-pasca.undiksha.ac.id/index.php/jurnal_ipa/article/view/796
- McKagan, S., Perkins, K., Dubson, M., Malley, C., Reid, S., LeMaster, R., & Wieman, C. (2008). Developing and researching phet simulations for teaching quantum mechanics. *American Journal of Physics*, 76(4), 406-417. <https://doi.org/10.1119/1.2885199>
- Ndihokubwayo, K., Uwamahoro, J., & Ndayambaje, I. (2020). Effectiveness of PhET Simulations and YouTube Videos to Improve the Learning of Optics in Rwandan Secondary Schools. *African Journal of Research in Mathematics, Science and Technology Education*, 24(2), 253-265. <https://doi.org/10.1080/18117295.2020.1818042>
- Perkins, K., Adams, W., Dubson, M., Finkelstein, N., Reid, S., Wieman, C., & LeMaster, R. (2008). PhET: interactive simulations for teaching and learning physics, 702-709. https://doi.org/10.1142/9789812813787_0097
- Planinić, M., Ivanjek, L., Sušac, A., & Milin-Šipuš, Ž. (2013). Comparison of university students' understanding of graphs in different contexts. *Physical Review Special Topics - Physics Education Research*, 9(2). <https://doi.org/10.1103/physrevstper.9.020103>
- Salvetti, F., Rijal, K., Owusu-Darko, I., & Prayogi, S. (2023). Surmounting Obstacles in STEM Education: An In-depth Analysis of Literature Paving the Way for Proficient Pedagogy in STEM Learning. *International Journal of Essential Competencies in Education*, 2(2), 177-196. <https://doi.org/10.36312/ijece.v2i2.1614>
- Saudelli, M., Kleiv, R., Davies, J., Jungmark, M., & Mueller, R. (2021). PhET simulations in undergraduate physics. *Brock Education Journal*, 31(1). <https://doi.org/10.26522/brocked.v31i1.899>
- Su, Y. (2010). Can we feel physics concepts? *Physics Education*, 45(5), 454-455. <https://doi.org/10.1088/0031-9120/45/5/f02>
- Suhirman, S., Prayogi, S., & Asy'ari, M. (2021). Problem-Based Learning with Character-Emphasis and Naturalist Intelligence: Examining Students' Critical Thinking and Curiosity. *International Journal of Instruction*, 14(2), 217-232. <https://doi.org/10.29333/iji.2021.14213a>

- Sušac, A., Bubić, A., Kazotti, E., Planinić, M., & Palmović, M. (2018). Student understanding of graph slope and area under a graph: a comparison of physics and nonphysics students. *Physical Review Physics Education Research*, 14(2). <https://doi.org/10.1103/physrevphyseducre.14.020109>
- Susilawati, A., Halim, A., Syukri, M., Khaldun, I., & Susanna, S. (2022). Effect of using physics education technology (PhET) simulation media to enhance students' motivation and problem-solving skills in learning physics. *Jurnal Penelitian Pendidikan IPA*, 8(3), 1157-1167. <https://doi.org/10.29303/jppipa.v8i3.1571>
- Tao, J., Wang, S., Wang, J., & Yong-jun, M. (2018). Effect of different instructional methods on students' conceptual change regarding electrical resistance as viewed from a synthesized theoretical framework. *Eurasia Journal of Mathematics Science and Technology Education*, 14(7). <https://doi.org/10.29333/ejmste/90592>
- Verawati, N. N. S. P., Handriani, L. S., & Prahani, B. K. (2022). The Experimental Experience of Motion Kinematics in Biology Class Using PhET Virtual Simulation and Its Impact on Learning Outcomes. *International Journal of Essential Competencies in Education*, 1(1), 11-17. <https://doi.org/10.36312/ijece.v1i1.729>
- Yanto, F., Festiyed, F., & Enjoni, E. (2021). Problem based learning model for increasing problem solving skills in physics learning. *Jurnal Ilmu Pendidikan Fisika*, 6(1), 53. <https://doi.org/10.26737/jipf.v6i1.1870>
- Yusuf, M., Ardhuha, J., Hikmawati, H. (2022). Pengembangan Perangkat Pembelajaran Model *Problem Based Learning* untuk Meningkatkan Pemahaman Konsep Fisika dan Kemampuan Berpikir Kritis Peserta Didik. *Jurnal Ilmiah Profesi Pendidikan*, 7(2), 250-258. <https://doi.org/10.29303/jipp.v7i2.457>
- Zafeiropoulou, M., Volioti, C., Keramopoulos, E., & Sapounidis, T. (2021). Developing Physics Experiments Using Augmented Reality Game-Based Learning Approach: A Pilot Study in Primary School. *Computers*, 10(10), 126. <https://doi.org/10.3390/computers10100126>