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# The Impact of PhET-Assisted Problem-Solving Model on Enhancing Students' Physics Problem-Solving Skills in Indonesian High Schools

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**Abstract:** This study investigates the impact of a PhET-assisted problem-solving model on high school students' physics problem-solving skills, especially in resource-limited educational settings in Indonesia. Conducted as a quasi-experimental study with a non-equivalent control group pretest-posttest design, the research involved 50 students from SMAN 10 Kendari, divided into an experimental group receiving instruction through the PhET-assisted model and a control group following traditional teaching methods. The intervention consisted of structured learning sessions incorporating PhET simulations, designed to engage students actively with physics concepts through virtual experiments. Data were collected using a 10-item problem-solving test and analyzed using a one-way ANOVA to determine the statistical significance of differences in performance between groups. Results revealed a significant improvement in the experimental group, with a mean increase of 47.91 points from pretest to posttest ($M = 83.54$, $SD = 15.22$) compared to the control group's improvement of 39.11 points ($M = 74.48$, $SD = 12.78$). The ANOVA results ($F = 23.526$, $p < 0.001$) confirm that the PhET-assisted model significantly enhanced students' problem-solving skills. These findings suggest that PhET simulations can be an effective tool for improving physics learning outcomes in schools with limited access to laboratory resources. Integrating PhET simulations into the physics curriculum could provide students with accessible, interactive learning experiences that bridge the gap in traditional laboratory access, fostering a deeper understanding and application of physics concepts.

**Keywords:** PhET Simulations, Problem-solving Model, Physics Education, Virtual Laboratory, Physics Problem-Solving Skills

## INTRODUCTION

Physics education is vital in equipping students with the analytical and problem-solving skills required to understand and apply scientific principles. However, Indonesian high schools, especially those in rural or under-resourced areas, face significant challenges in delivering effective physics education due to limitations in laboratory facilities and instructional resources. This gap in resources creates an inequitable learning environment where students in disadvantaged settings miss out on hands-on experiences critical to understanding complex physics concepts and applying them in real-world contexts (Gozali & Paik, 2022; Johan et al., 2022). Consequently, these disparities hinder students' engagement, interest, and overall achievement in physics, posing substantial obstacles to their academic progress.

Many high schools across Indonesia, particularly those in remote regions, lack access to essential laboratory equipment and materials, which creates a divide between urban and rural schools in terms of educational quality. Studies indicate that urban

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schools typically benefit from better laboratory facilities and instructional resources than their rural counterparts (Johan et al., 2022). Practical laboratory work is crucial for physics education, as it allows students to apply theoretical knowledge and engage directly with physical phenomena, fostering critical thinking and problem-solving abilities. Without these practical experiences, students struggle to connect abstract physics theories with real-world applications, which impacts both their understanding and problem-solving skills (Apriyanti et al., 2020).

Moreover, the quality of teaching resources in Indonesian high schools is often inadequate, with a lack of modern digital tools and ineffective instructional materials that do not align with contemporary educational demands. Many physics teachers also lack training in using advanced educational technologies, which results in less engaging learning environments, particularly in resource-limited settings. This gap in teacher preparation and resource quality contributes to low student motivation and interest in physics, as students are often unable to see the relevance of what they are learning. This lack of engagement further complicates the already challenging task of teaching physics effectively (Reza, 2023).

Problem-solving is a central skill in physics, involving the analysis of complex situations, application of scientific principles, and formulation of solutions. However, students in many under-resourced Indonesian schools are unable to develop these skills adequately due to limited access to laboratory facilities and interactive instructional tools. Laboratory work encourages students to experiment, make observations, and apply theoretical knowledge in practical contexts, developing the critical thinking needed for effective problem-solving. In the absence of these hands-on experiences, students often resort to memorization and formulaic problem-solving, which fails to provide a deep understanding of physics principles and hinders their ability to apply these concepts in different contexts (Hakim, 2023). This lack of hands-on engagement leads to a cycle of disengagement, as students perceive physics as difficult and disconnected from real-world applications (Apriyanti et al., 2020).

In response to these limitations, PhET simulations have emerged as a valuable educational tool, particularly in the context of physics education. PhET, an open-source platform offering interactive simulations, provides a virtual laboratory experience that allows students to experiment with variables, observe outcomes, and explore physics concepts in a controlled, accessible environment. These simulations are cost-effective and require minimal physical resources, making them ideal for schools lacking traditional laboratory facilities. By simulating hands-on experiences, PhET simulations bridge the gap between theoretical and practical knowledge, enabling students to visualize and interact with abstract physics concepts in ways that traditional lectures cannot offer (Prihatiningtyas, 2024; Banda & Nzabahimana, 2022).

PhET simulations offer significant benefits for students, particularly in resource-limited schools. They make abstract physics concepts more tangible by enabling students to visualize and manipulate variables in real-time, such as exploring principles of motion, energy, and waves. This interactive approach aligns with constructivist learning theories, emphasizing active knowledge-building through exploration and experimentation. By engaging with PhET simulations, students develop a deeper understanding of physics concepts and improve their problem-solving skills through interactive learning, which fosters both critical thinking and analytical abilities (Doyan et al., 2021).

A growing body of research demonstrates that PhET simulations can significantly enhance students' understanding of physics concepts and problem-solving skills. Studies by Verawati et al. (2022) and Eleo (2024) indicate that students who engage with PhET simulations perform better in understanding topics such as electricity, mechanics, and wave theory than those taught through traditional methods. Khaeruddin and Bancong (2022) further found that students using PhET simulations showed improved critical thinking skills, as the simulations provided a virtual experimental setting where students could actively engage with physics principles. These findings underscore PhET simulations' potential in fostering deeper engagement with physics concepts, ultimately enhancing students' problem-solving capabilities.

Furthermore, PhET simulations have been shown to boost student motivation and engagement. Traditional classroom methods often fail to sustain students' interest, especially when dealing with abstract scientific concepts. PhET simulations, however, offer a more dynamic and enjoyable learning experience. During the COVID-19 pandemic, PhET simulations played a crucial role in keeping students engaged in physics learning, even when physical laboratories were inaccessible (Efendi & Sartika, 2021). This heightened engagement leads to better academic performance and knowledge retention, as students are more likely to be active participants in their learning process.

PhET simulations support constructivist learning approaches, which advocate that students learn most effectively through active participation and knowledge construction. Constructivist frameworks emphasize that students build understanding through exploration, experimentation, and reflection—key elements that PhET simulations facilitate. Research shows that simulations like PhET promote deeper learning by providing students with an interactive, learner-centered environment. Mintii (2023) highlights that STEM simulations not only enhance students' conceptual understanding but also boost their confidence in applying scientific knowledge to solve complex problems.

Studies by Yap et al. (2021) and Wibowo et al. (2022) provide additional evidence of virtual simulations' role in developing problem-solving skills. These studies found that virtual laboratories enhance students' engagement, motivation, and critical thinking skills, as the immersive experience allows students to apply theoretical knowledge to practical scenarios. By allowing students to manipulate variables, test hypotheses, and analyze outcomes in a virtual setting, PhET simulations replicate the scientific inquiry process, helping students develop critical 21st-century skills needed for effective problem-solving. This simulation-based learning encourages exploration and interaction, making PhET a valuable tool for enhancing students' physics learning experiences.

Despite the promise of PhET simulations in improving physics education, there remains a critical research gap concerning their impact on students' problem-solving skills, particularly within Indonesian high schools where laboratory facilities are limited. While existing studies have explored general improvements in conceptual understanding and student engagement, little research has been conducted on how PhET simulations specifically enhance students' abilities to solve complex physics problems. Addressing this gap is essential, especially in Indonesia, where disparities in resources present significant barriers to effective science education.

This study aims to address this research gap by investigating the effect of a problem-solving learning model supported by PhET simulations on high school students' physics problem-solving abilities. Focusing on SMAN 10 Kendari, a school with limited access to laboratory facilities, this research seeks to determine whether integrating PhET simulations into problem-solving activities can significantly improve students' understanding of physics concepts and enhance their critical thinking and analytical skills. By examining the use of PhET in a resource-limited setting, this study aims to provide insights into the potential of virtual laboratories to bridge resource gaps in Indonesian physics education and develop students' problem-solving abilities. This research intends to explore whether PhET simulations can serve as a viable alternative to traditional laboratories, equipping students with the problem-solving skills needed for academic and practical success in physics. Ultimately, this study aims to underscore the potential of virtual laboratories to close resource gaps in Indonesian schools and improve educational outcomes in physics.

## METHOD

This quantitative study utilized a quasi-experimental design with a non-equivalent control group pretest-posttest format to evaluate the effectiveness of a PhET-assisted problem-solving model on students' physics problem-solving abilities. The study was conducted at SMAN 10 Kendari during the 2021/2022 school year, involving two class groups designated as the experimental and control groups. The experimental group (class XI IA2) was exposed to the problem-solving model with PhET media, while the control group (class XI IA3) followed conventional instructional methods without simulations. Table 1 illustrates the non-equivalent control group design applied in this study.

**Table 1.** Non-equivalent Control Group Design

| Group | Pretest | Treatment | Posttest |
|---|---|---|---|
| E | O1 | X | O2 |
| K | O3 | X | O4 |

### Sample

The sampling technique was purposive, selecting class groups based on their availability, the students' familiarity with digital learning tools, and logistical constraints. This approach aligns with Arviani (2023), who used a non-equivalent control group design in a similar educational setting, highlighting the practicality of this approach when random assignment is not feasible. Class XI IA2, consisting of 25 students, served as the experimental group, while Class XI IA3, also with 25 students, was designated as the control group. Students were included if they were actively enrolled in the selected classes and had no prior experience with PhET simulations, ensuring that the study measured the impact of the intervention accurately.

### Instruments and Data Collection

The primary instrument was a description test comprising 10 problem-solving items, scored on a 0–100 scale. This test was developed to measure students' ability to apply physics concepts in problem-solving contexts. Prior to administering the test, the instrument underwent a validity and reliability assessment to ensure its effectiveness in capturing relevant data. Following these assessments, the instrument was confirmed to meet the criteria for validity and reliability in educational research.

In addition to the test, a non-test instrument, which consisted of a student response sheet, was used to assess the practicality and acceptability of the PhET-assisted learning model. This non-test instrument gathered qualitative feedback from students regarding their experience with the PhET simulations, enabling the researchers to gauge the perceived utility and engagement levels associated with the learning model. Table 2 outlines the scoring criteria used to assess students' responses regarding the practicality of the PhET-assisted problem-solving model, with interval scores ranging from "Very Not Good" to "Very Good."

**Table 2.** Practicality Criteria for PhET-Assisted Problem-Solving Model

| Interval Score | Category |
|---|---|
| $1.00 \leq P < 1.50$ | Very Not Good |
| $1.51 \leq P < 2.50$ | Not Good |
| $2.51 \leq P < 3.50$ | Good |
| $3.51 \leq P \leq 4.00$ | Very Good |

### Procedure

#### *Implementation of the PhET-Assisted Problem-Solving Model*

The intervention for the experimental group involved a structured problem-solving model supported by PhET simulations, implemented over a series of sessions. Each session was approximately 60 to 90 minutes, following recommendations from

"Towards the Development of Research Skills of Physics Students through the Use of Simulators: A Case Study" (2023). The sessions were structured into the following phases.

1. Introduction Phase (10-15 minutes): The teacher introduced each physics topic and provided an overview of the relevant concepts. For instance, in a session on electric circuits, the teacher explained basic circuit principles and laws before guiding students into the simulation activity.
2. Exploration Phase (30-45 minutes): Students worked in pairs or small groups to explore the PhET simulations, manipulating variables and observing outcomes. This interactive, collaborative setting aimed to promote engagement and allow students to discuss and hypothesize outcomes together. Simbolon & Silalahi (2023) emphasize that such guided inquiry encourages students to actively engage with scientific concepts, fostering critical thinking.
3. Guided Inquiry (15-20 minutes): The teacher provided specific questions to guide students' exploration, focusing their attention on key learning objectives. For example, students using a simulation on force and motion were prompted to predict the effects of changing mass on acceleration. This structured guidance aligns with Danuarteu et al. (2023), who suggest that guiding questions are essential for helping students connect theory with practice.
4. Reflection and Discussion Phase (15-20 minutes): At the end of each session, students participated in a class discussion to share findings, discuss observations, and relate their experiences to real-world applications. This reflective phase was crucial for consolidating understanding and allowed students to articulate their thought processes and learning outcomes, as recommended by Lahlali (2023).

The control group, in contrast, received conventional instruction through lectures, demonstrations, and group discussions without the use of PhET simulations. This difference allowed for a comparison of the effectiveness of the PhET-assisted problem-solving model versus traditional teaching methods.

**Data Analysis**

To evaluate the impact of the PhET-assisted model on students' problem-solving abilities, the study employed a one-way Analysis of Variance (ANOVA) to compare pretest and posttest scores between the experimental and control groups. ANOVA was chosen because it enables researchers to determine whether there are statistically significant differences between group means, accounting for within-group variance. This approach is particularly suited for quasi-experimental designs, as it provides a robust statistical measure to assess the effectiveness of interventions.

In this study, a p-value of less than 0.05 was considered statistically significant, indicating that observed differences in posttest scores between the experimental and control groups were unlikely to be due to chance. ANOVA's ability to handle multiple sources of variance (between and within groups) made it an appropriate tool for analyzing the pretest-posttest data, thereby enhancing the reliability and validity of the results. This structured approach to design, sampling, procedure, and analysis provides a rigorous methodological framework to evaluate the PhET-assisted problem-solving model's impact on student learning, ensuring that the findings are both reliable and meaningful for educational practice.

## RESULT AND DISCUSSION

**Descriptive results**

In this study, a pretest-posttest design was implemented to evaluate the impact of the PhET-assisted problem-solving model on students' physics problem-solving abilities. By comparing the pretest and posttest results of the experimental and control groups, the study aims to provide a clear picture of the effectiveness of PhET simulations compared to traditional instructional methods. The pretest measured the baseline knowledge and problem-solving skills of students in both groups before the intervention, while the posttest assessed their skills after the experimental group participated in PhET-assisted learning and the control group received conventional instruction. The initial analysis of pretest scores revealed comparable baseline abilities in both groups. This equivalence at the outset is crucial for ensuring that any differences in posttest scores can be attributed to the instructional method rather than pre-existing disparities in knowledge or skill levels.

Table 3 summarizes the pretest scores, showing a mean score of 35.63 (SD = 10.45) for the experimental group and 35.37 (SD = 9.85) for the control group. These close mean values, along with the overlapping standard deviations, indicate a similar starting point in physics problem-solving ability between the two groups. Such comparability in pretest results supports the validity of the post-intervention comparison by confirming that the groups had a nearly identical foundation in problem-solving skills related to physics prior to the intervention.

**Table 3.** The summarizes of pretest scores

| Group | Pretest Mean (SD) |
|---|---|
| Experimental | 35.63 (10.45) |
| Control | 35.37 (9.85) |

Following the intervention (Table 4), the posttest scores were recorded to measure the development of problem-solving skills in both groups. The experimental group, which received instruction through the PhET-assisted problem-solving model, demonstrated a substantial improvement, with a posttest mean score of 83.54 (SD = 15.22). This improvement represents an increase of nearly 48 points from the pretest score, indicating a significant enhancement in problem-solving ability facilitated by the interactive learning model. In contrast, the control group, which continued with conventional instructional methods, achieved a posttest mean score of 74.48 (SD = 12.78), showing an increase of approximately 39 points from their pretest results. While this score represents a notable improvement, it falls short of the gains made by the experimental group, suggesting that traditional teaching methods may not be as effective in fostering significant development in problem-solving skills as the PhET simulation-based approach.

**Table 4.** The summarizes of pretest scores

| Group | Pretest Mean (SD) | Posttest Mean (SD) | Mean Improvement |
|---|---|---|---|
| Experimental | 35.63 (10.45) | 83.54 (15.22) | 47.91 |
| Control | 35.37 (9.85) | 74.48 (12.78) | 39.11 |

These data highlight the effectiveness of PhET simulations as an instructional tool, as evidenced by the higher score increase in the experimental group compared to the control group. The nearly 8-point differential in mean improvement underscores the value of interactive and visually engaging learning tools in enhancing students' understanding and application of physics concepts. To better illustrate the differences in improvement between the two groups, Figure 1 presents a visual comparison of pretest and posttest scores. The bar graph shows the mean scores for each group before and after the intervention, with an observable, significant increase in the posttest scores for the experimental group. In Figure 1, it is evident that while both groups experienced improvement from the pretest to the posttest, the experimental group's performance surpasses that of the control group by a notable margin. This graphic representation supports the quantitative findings and provides a visual confirmation of the greater efficacy of the PhET-assisted model in improving physics problem-solving abilities.

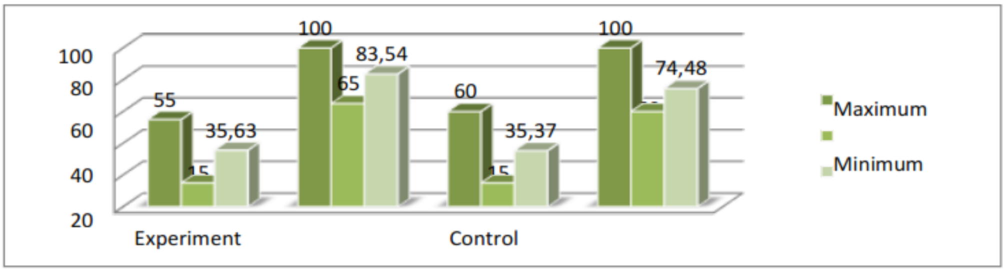


**Figure 1.** The differences of improvement between the two groups

**Detailed Statistical Analysis on Students' Problem-Solving Skills**

To confirm the statistical significance of the observed differences, a one-way analysis of variance (ANOVA) was conducted. The ANOVA assessed whether the mean posttest scores of the experimental and control groups differed significantly, providing a robust statistical basis for evaluating the effectiveness of the PhET-assisted learning model.

As shown in Table 5, the ANOVA yielded an F-ratio of 23.526 with degrees of freedom (df) of 1 and 45 for the between-group and within-group variance, respectively. The corresponding p-value was less than 0.001, indicating a statistically significant difference between the groups. This result strongly supports the hypothesis that the PhET-assisted problem-solving model contributes more effectively to students' physics problem-solving abilities than traditional teaching methods.

**Table 5.** Hypothesis Test Result

| Source | Sum of Squares | df | Mean Square | F | p-value |
|---|---|---|---|---|---|
| Between Groups | 1696.856 | 1 | 1696.856 | 23.526 | <.001 |
| Within Groups | 3245.697 | 45 | 72.127 | | |
| Total | 4942.553 | 46 | | | |

The high F-value and low p-value ($< 0.001$) substantiate the conclusion that the PhET-assisted learning model had a significant positive impact on students' ability to solve physics problems. The ANOVA confirms the reliability of the observed improvement in the experimental group's performance, underscoring the efficacy of simulation-based instruction.

The mean improvement for the experimental group (47.91 points) far exceeded that of the control group (39.11 points), further indicating the strength of the PhET-assisted model in enhancing problem-solving abilities. This improvement can be attributed to the interactive nature of PhET simulations, which allow students to engage actively with physics concepts through visual and manipulative experiences. These hands-on activities likely promote a deeper understanding and application of abstract ideas, contributing to the substantial increase in problem-solving skills observed in the experimental group.

The significance of these findings is reinforced by the low p-value from the ANOVA, which confirms that the difference in posttest scores between the groups is not due to random chance. Instead, it suggests that the intervention had a true effect on students' performance, validating the hypothesis that PhET simulations provide a superior learning experience compared to conventional teaching methods.

The results of this pretest-posttest analysis have important implications for physics education, particularly in resource-limited settings. The considerable gains observed in the experimental group suggest that PhET simulations can effectively substitute for physical laboratory experiences, offering a feasible alternative for schools lacking access to lab resources. By providing students with the opportunity to visualize, manipulate, and experiment with physics concepts virtually, PhET simulations address some of the key limitations of traditional lecture-based instruction, such as a lack of interactivity and engagement.

Furthermore, these findings support the integration of PhET simulations into physics curricula as a means of enhancing students' problem-solving skills. Given the statistical significance and practical relevance of the improvements observed, educational institutions—particularly those with limited laboratory facilities—should consider incorporating PhET simulations into their teaching strategies to provide students with a more interactive and effective learning experience.

The pretest and posttest data analysis clearly demonstrates the value of PhET simulations in improving physics problem-solving skills. The experimental group's substantial improvement, corroborated by a statistically significant ANOVA result, highlights the potential of simulation-based learning models to enhance students' understanding and application of physics concepts. By engaging students in active problem-solving tasks, PhET simulations offer a dynamic and accessible tool for schools, particularly in areas where traditional laboratory resources are unavailable or insufficient.

**Discussion**

The significant improvement observed in the experimental group's problem-solving abilities aligns with a growing body of research on the effectiveness of interactive simulations in physics education. This study's results, as presented in Table 1 and Table 2, provide evidence for the effectiveness of the PhET-assisted problem-solving model. Specifically, students in the experimental group displayed an improvement of 47.91 points from pretest to posttest (Pretest Mean = 35.63, Posttest Mean = 83.54), which was notably higher than the 39.11-point increase observed in the control group (Pretest Mean = 35.37, Posttest Mean = 74.48). This improvement underscores the capacity of PhET simulations to foster deeper engagement and understanding in physics problem-solving tasks.

Studies by Salame & Makki (2021) and Sari et al. (2021) have documented similar benefits, with interactive simulations improving students' grasp of abstract concepts by making them visually and manipulatively accessible. Salame & Makki reported that PhET's dynamic graphics allowed students to interactively explore complex topics, which enhanced their understanding and helped bridge the gap between theoretical and practical knowledge. Likewise, Sari et al. (2021) found that PhET simulations facilitated improved conceptual understanding of physics by allowing students to visualize and experiment with variables, an advantage also demonstrated in the present study's posttest outcomes.

The findings of this study are also consistent with research by Suhirman & Prayogi (2023) and Kurnia et al. (2020), which underscore the role of PhET simulations in developing critical thinking and problem-solving skills. Suhirman & Prayogi observed that problem-based learning (PBL) models supported by PhET simulations significantly improved students' ability to analyze and solve physics problems, promoting a hands-on approach that actively engages learners. Similarly, Kurnia et al. (2020) demonstrated that guided inquiry models using PhET enhanced students' analytical capabilities, a finding mirrored in this study by the experimental group's higher posttest scores compared to the control group.

Table 2, displaying the ANOVA results, further corroborates the statistical significance of the observed differences. The F-ratio of 23.526 and a p-value of less than 0.001 confirm that the PhET-assisted model provided a significant advantage in problem-solving development over traditional methods. This aligns with Mercado et al. (2014), who noted that conventional, lecture-based teaching often fails to equip students with the practical problem-solving skills required for real-world applications. In contrast, the interactive and explorative nature of PhET simulations in this study provided students with opportunities to test hypotheses, manipulate variables, and actively engage with the physics material, resulting in enhanced problem-solving abilities.

***Practical Implications for Indonesian Schools with Limited Resources***

The substantial improvements in the experimental group highlight the potential of PhET simulations to address educational challenges in Indonesian high schools, particularly those with limited laboratory resources. For many Indonesian schools, especially those in rural areas, the absence of well-equipped physical labs restricts students' opportunities for hands-on experimentation, which is crucial for understanding physics concepts. The PhET simulations offer a viable alternative to physical labs by providing students with an interactive platform where they can engage in virtual experimentation. This approach is particularly beneficial for settings with limited funding and infrastructure.

As illustrated by the posttest results (Mean Improvement = 47.91 in the experimental group), the PhET-assisted model effectively compensates for the lack of traditional lab facilities. Studies by Banda & Nzabahimana (2022) and Sari et al. (2021) support this implication, noting that PhET simulations are highly adaptable to various educational contexts, including low-resource and remote settings. Sari et al. (2021) specifically found that PhET-based instruction increased student engagement and understanding of physics concepts even in challenging learning environments, an advantage that is echoed by the experimental group's significant posttest improvements in this study.

Moreover, Table 1's findings illustrate how PhET simulations could help equalize educational outcomes by enabling students from resource-limited schools to experience experimental physics learning similar to those in more equipped schools. The mean posttest score of 83.54 in the experimental group, compared to the control group's 74.48, suggests that simulations can bridge the gap created by resource limitations, providing a more equitable learning experience across diverse school settings.

For teachers, integrating PhET simulations into the curriculum offers a new instructional strategy that enhances student interaction with complex physics concepts. Banda & Nzabahimana (2022) reported that the use of simulations increased student motivation and academic performance, an observation that aligns with the higher mean improvement in the experimental group. By blending PhET simulations with traditional instruction, teachers can create a more dynamic classroom that caters to a range of learning styles, increasing both student engagement and knowledge retention. This combined approach is particularly valuable in classrooms where students may struggle with theoretical content, as the visual and interactive nature of simulations helps make abstract concepts more accessible.

***Benefits of PhET Simulations for Enhancing Student Engagement and Motivation***

One of the critical findings of this study is the role of PhET simulations in boosting student engagement and motivation, which are essential for effective learning. The experimental group's higher improvement rate in problem-solving skills reflects not only a better understanding of physics concepts but also greater interest in the learning process. Research by Azzubairiyah et al. (2022) supports this conclusion, noting that PhET simulations provide a stimulating environment that actively involves students in exploring scientific principles, which fosters sustained engagement.

The posttest results (Mean = 83.54 for the experimental group) provide quantitative support for the notion that PhET simulations promote a more engaging learning experience. This aligns with Banda & Nzabahimana (2022), who found that students who learned through PhET-based activities displayed increased motivation, resulting in higher academic achievement. The study by Efendi & Sartika (2021) conducted during the COVID-19 pandemic further confirmed that PhET simulations can maintain student interest and engagement in remote or hybrid settings, offering flexibility that is crucial for modern education. This flexibility, combined with PhET's interactive features, makes simulations particularly effective in sustaining students' interest in physics, as evidenced by the notable performance gains observed in this study.

The positive effects on motivation and engagement are particularly significant for Indonesian schools, where physics is often perceived as challenging. By making the learning process more interactive and enjoyable, PhET simulations could help change students' attitudes toward physics, encouraging them to approach the subject with curiosity rather than apprehension. As shown by the experimental group's greater posttest improvement, simulations have the potential to shift student perceptions, making physics more approachable and fostering a learning environment where students are more likely to actively participate and retain information.

**Limitations of the Study**

While this study provides valuable insights into the benefits of PhET simulations, several limitations must be acknowledged. First, the sample size was relatively small, consisting of only two class groups from a single school. Although the ANOVA results (Table 2, $F = 23.526$, $p < .001$) confirm statistical significance, a larger sample size across multiple schools would provide a more robust evidence base and increase the generalizability of the findings. Another limitation concerns the demographic scope of the study, which focused exclusively on high school students at SMAN 10 Kendari. While the observed improvements in problem-solving skills are encouraging, the applicability of PhET simulations may vary across different age groups and educational levels. Future research should explore the impact of PhET simulations on younger students or college-level learners to determine whether the benefits observed in this study extend to other educational stages. Additionally, this study focused solely on physics education, limiting the findings to a single STEM subject. Although PhET offers simulations for a variety of subjects, including chemistry and biology, it remains uncertain whether the same improvements in problem-solving skills would occur in these disciplines. Further research is recommended to assess the effectiveness of PhET simulations in other STEM areas, providing a more comprehensive understanding of the potential applications of this educational tool.

To build upon the findings of this study, future research should adopt a broader approach to better understand the potential and limitations of PhET simulations across diverse educational contexts. First, expanding the sample size to include students from multiple schools across various regions and demographics would enhance the generalizability of findings and provide insights into how PhET simulations perform in different learning environments. Additionally, future studies should consider longitudinal designs to assess the long-term retention of problem-solving skills and conceptual understanding fostered by PhET simulations, as this study focused on short-term improvements. Exploring the effectiveness of PhET simulations in other STEM fields—such as chemistry, biology, and mathematics—would also provide a more comprehensive understanding of the tool's adaptability and impact across disciplines. Research into the most effective implementation strategies, such as blended learning models or flipped classroom approaches, could further help educators maximize the educational benefits of PhET simulations. Lastly, studies that investigate teachers' perspectives on integrating PhET into their instructional practices would be valuable in identifying practical challenges and professional development needs, as these factors can influence the successful adoption of simulation-based learning in resource-limited classrooms.

## CONCLUSION

This study demonstrates the effectiveness of PhET-assisted problem-solving models in enhancing high school students' physics problem-solving skills, particularly in resource-limited settings. The significant improvement observed in the experimental group, as compared to the control group, underscores the value of interactive, simulation-based learning in making abstract physics concepts more accessible and engaging. The findings align with existing literature, which highlights the capacity of PhET simulations to foster critical thinking, analytical skills, and deeper understanding through interactive, student-centered exploration. The statistical analysis confirms that PhET simulations significantly enhance students’ ability to apply physics principles in problem-solving, a skill often underdeveloped through traditional teaching methods. Therefore, PhET simulations represent a promising educational tool for bridging resource gaps and promoting equitable learning opportunities, particularly in contexts where physical laboratory resources are scarce.

## RECOMMENDATION

Building on these findings, future research should seek to broaden the scope and applicability of PhET simulations in diverse educational contexts. Increasing the sample size and including students from various schools and regions would provide a more comprehensive perspective on how PhET simulations impact different learning environments and demographics. Longitudinal studies could further assess the long-term retention of problem-solving skills and conceptual understanding gained through PhET simulations, offering insights into their sustained educational value. Additionally, exploring the use of PhET simulations across other STEM subjects, such as chemistry and biology, would determine whether the tool’s benefits extend beyond physics education. Future research should also investigate optimal strategies for integrating PhET simulations, such as blended learning or flipped classroom models, to maximize their impact on student learning. Finally, studies examining teachers' perceptions and experiences with PhET simulations could help identify necessary professional development and practical considerations, supporting more effective adoption of these tools in diverse classroom settings.

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