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Original Research

Impact of PhET Simulation-Assisted Problem-Based Learning Model on Students' Problem-Solving Skills

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ABSTRACT

This study aims to examine the effect of Problem-Based Learning (PBL) assisted by PhET simulation on students' problem-solving abilities. Using a quasi-experimental research design with a Nonequivalent Control Group model, this study involved 146 students from four classes, divided into two groups, namely the experimental group that used the PBL model with PhET simulation assistance and the control group that followed the conventional learning method. After a pretest to measure initial problem-solving skills, the experimental group underwent PBL with PhET simulations, while the control group used traditional teaching methods. The results showed that both groups experienced improvement, but the experimental group demonstrated more significant improvement, with higher N-gain values (0.630 compared to 0.407) and larger effect sizes (Cohen's d = 3.52 compared to 2.19). Statistical analysis using the Mann-Whitney U test revealed significant differences in posttest scores, confirming that the PBL model assisted by PhET simulations is more effective in enhancing problem-solving skills compared to conventional learning methods. These findings emphasize the importance of implementing interactive learning approaches in improving students' cognitive abilities, particularly in physics education.

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1. INTRODUCTION

Education plays a crucial role in developing human potential and resources, shaping mindsets that can produce individuals ready to compete in an increasingly interconnected and globalized world (Taqwa et al., 2024; 2025). With the ever-evolving changes of the times, educational institutions are required to adapt quickly and provide learning that is relevant to today's global challenges. Advances in technology, communication, and shifts in social and economic structures influence many aspects of life, including the world of education. Therefore, an educational approach is needed that not only prioritizes knowledge acquisition but also skills that enable students to survive and excel in the face of various changes. 21st-century education requires a balance between academic content mastery and the development of 21st-century skills (Martinez, 2022; González-Pérez, 2022), such as critical thinking, creativity, collaboration, and the ability to solve complex problems. In this case, technology plays an important role as an element that can facilitate and enrich the learning process, enabling students to be more actively and independently involved in finding solutions to the challenges they face. In addition, 21st-century learning emphasizes the importance of digital literacy and media literacy, which enable students to not only access information but also sort and use it effectively in a broader context (Effendi & Wahidy, 2019).

21st-century education aims to produce individuals with deep knowledge and high skills, who not only master theory but are also able to apply it in everyday life. One effective learning approach to achieve this goal is the Problem-Based Learning (PBL) model, which challenges students to engage directly with real-world problems, develop teamwork skills, and learn to solve problems through investigation and collaboration (Mustika et al., 2018). Through the PBL model, students not only gather knowledge but are also encouraged to hone their critical thinking skills and ability to work independently and in groups. The success of a learning model lies in its ability to accommodate various learning styles and create relevant and engaging learning experiences. The use of an appropriate learning model will greatly influence students' understanding of the subject matter as well as the development of their attitudes and skills. Thus, students not only gain knowledge but also experience the direct benefits of the learning process (Hafid &Japeri, 2025). However, the implementation of the PBL model will be more optimal if combined with methods that support exploration and direct experience, one of which is the practicum method, which allows students to actively seek knowledge through conversation and direct experimentation.

The practical method is highly effective in the context of science education, particularly in physics, as it provides students with opportunities to explore abstract concepts directly through experiments and observations. Physics, as one of the foundational branches of science underlying technological advancement, requires a deeper understanding through an approach that is not only theoretical but also practical. In physics learning, experiments are a very important tool to help students understand concepts that often feel distant and difficult to grasp if only explained through theory or formulas (Susilawati et al., 2018). Therefore, it is important for teachers to design learning that not only provides conceptual understanding but also practical skills that can be applied in the real world. Unfortunately, in many cases, traditional approaches to physics teaching often focus more on verbal delivery of material and the use of formulas, without providing sufficient opportunities for students to actively engage in in-depth practical activities. This can lead to passive learning, making it difficult for students to develop problem-solving skills, which are an integral part of physics learning.

Problem-solving skills are one of the key skills that are essential in 21st-century education, as they not only help students understand the subject matter but also train them to think critically and creatively in the face of challenges. Problem-solving is not only a cognitive skill needed in learning, but also in everyday life (Alfat et al., 2025; Guner & Erbay, 2021). Students who are able to solve problems effectively will be better prepared to face challenging situations, both in the academic world and in the professional world (Susanto, 2019). Therefore, the development of problem-solving skills is vital, especially in physics learning, which is related to natural phenomena and experiments that require in-depth analysis and solutions. Many problems encountered in daily life can be solved with a problem-solving approach, and this is a skill that should be honed early on in school.

Based on observations and interviews conducted by researchers at a high school in East Java Province, it was found that most classroom learning uses a conventional learning model that emphasizes lectures and discussions. Although the discussion method provides opportunities for students to interact, learning tends to be passive and does not provide sufficient opportunities for students to develop practical and problem-solving skills. Furthermore, practical methods, which are very important for deepening the understanding of physics concepts, are rarely used due to limited equipment and damaged practical rooms caused by natural disasters. This results in low basic skills among students in understanding and applying physics concepts, as reflected in the low average scores of grade XI MIPA assignments, which are only around 49. Teachers' efforts to introduce technology using PowerPoint, Google tools, and YouTube in some physics lessons have increased students' interest, but the use of technology is limited to searching for learning references and online tutorials, without integrating technology more deeply into active and interactive learning.

Given this reality, an innovative learning approach is needed that combines technology with a learning model that encourages students to be more active in seeking solutions to existing problems, particularly in the context of physics laboratory experiments. One approach that can be used is the integration of the Problem-Based Learning model with the assistance of PhET simulations, which allow students to conduct virtual experiments and explore physics concepts interactively. PhET simulations offer students the opportunity to engage directly in experiments that may not be possible in a conventional physics laboratory, thereby enhancing their problem-solving skills and overcoming the limitations of practical tools. Learning media plays an important role in learning so that students can understand the material to the fullest extent possible (Khuzaini, 2024). Therefore, this study aims to examine the extent to which the Problem-Based

Learning model assisted by PhET simulations influences students' problem-solving abilities in physics learning.

2. METHOD

This study aims to examine the effect of the Problem-Based Learning (PBL) model assisted by PhET simulation on students' problem-solving abilities. The research design used is a quasi-experimental study, which aims to compare learning outcomes between two groups: an experimental group using the PBL model assisted by PhET simulation and a control group using conventional teaching methods. The research design applied is a Nonequivalent Control Group Design, in which two groups with similar characteristics are selected, but no randomization is performed, so that the comparison is made between existing groups.

In this study, there were four classes as samples, with a total number of 146 students (73 students in each of the experimental and control groups). The sampling technique used was purposive sampling, where the selection of samples was based on certain considerations, namely, the average final exam scores of the two groups were relatively the same. This was done so that the comparison between the two groups was fairer and valid, considering the similar initial characteristics of the two groups. Thus, the differences found in the research results could be more accurately attributed to the treatment given, not the initial differences in student abilities.

The instrument used to measure students' problem-solving abilities was a test consisting of 10 essay questions. These questions had undergone a validation process by experts and were also empirically tested to ensure the validity and reliability of the instrument. This problem-solving ability test aimed to measure the extent to which students could identify problems, analyze information, and find solutions to the problems given, which are the main skills in physics learning. Before the treatment began, both groups were given a pretest to determine the students' initial problem-solving abilities. This pretest also served to ensure that both groups had relatively the same level of ability before being given different treatments.

After the pretest, both classes were then given treatment during four learning sessions. The experimental group was given treatment using the PhET simulation-assisted Problem-Based Learning model, while the control group was given conventional learning methods. PhET simulations were used to provide a more interactive and in-depth learning experience related to difficult physics concepts by allowing students to conduct virtual experiments. After the treatment period was completed, both groups were given a post-test to measure the improvement in students' problem-solving skills after the treatment. The post-test consisted of questions similar to the pre-test to ensure that the observed changes were the result of the treatment given.

The results of the posttest were then analyzed using Microsoft Excel to calculate scores and process data. The data analysis consisted of several stages, namely a normality test to test the distribution of data in each group, a homogeneity test to ensure that both groups had similar variances, and an N-gain test to measure the improvement in students' abilities from the pretest to the posttest. In addition, a hypothesis test was conducted to determine whether there were significant differences between the two groups after being given different treatments. This hypothesis test aimed to examine whether the PhET simulation-assisted PBL model had a greater effect on improving problem-solving skills compared to conventional learning.

3. RESULTS AND DISCUSSION

3.1. Data Normality Test Results

This article begins with a presentation of the results of normality tests conducted to determine whether the data in the experimental and control groups are normally distributed. Normality tests were performed using two methods, namely Kolmogorov-Smirnov and Shapiro-Wilk, both of which test the suitability of data distribution with normal distribution.

The results of the normality tests in Table 1 show that all groups, both the experimental groups (PreE and PostE) and the control groups (PreC and PostC), are not normally distributed. In the PreC group (control group pretest), the significance value in the Kolmogorov-Smirnov test was 0.000, and in the Shapiro-Wilk test it was 0.015, both of which were less than 0.05, indicating that the data were not normally distributed. The same results were found in the PostC group (control group posttest), where the significance value in the Kolmogorov-Smirnov test was 0.000, and in the Shapiro-Wilk test was 0.046, both of which also indicate that the data are not normally distributed.

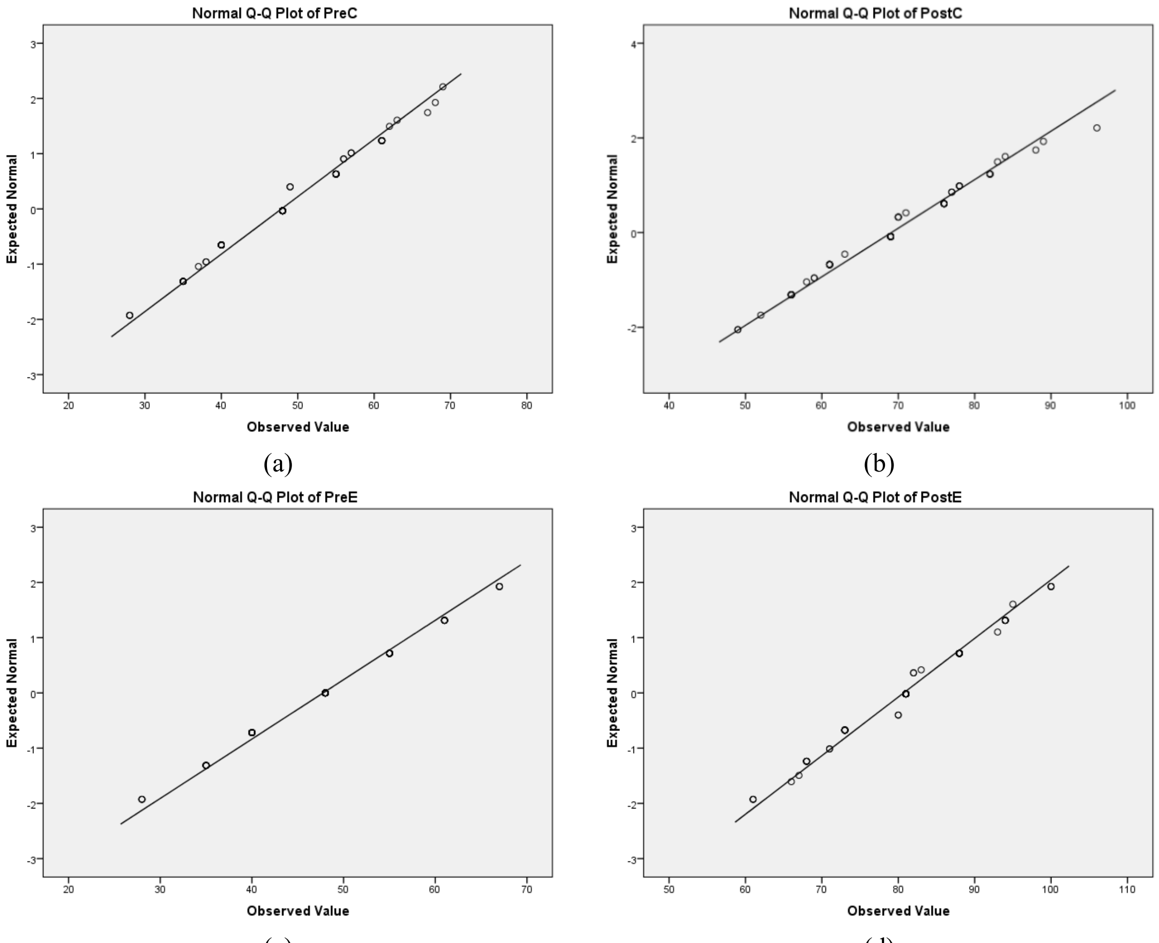
In the PreE group (experimental group pretest), the significance value in the Kolmogorov-Smirnov test was 0.000, and in the Shapiro-Wilk test it was 0.004, indicating that the data were not normally distributed. Similarly, in the PostE group (experimental group posttest), the significance value in the Kolmogorov-Smirnov test is 0.000, and in the Shapiro-Wilk test is 0.014, which also indicates that the data is not normally distributed.

Therefore, based on the results of the normality test, it can be concluded that the data from all tested groups (both pretest and posttest in the experimental and control groups) are not normally distributed, leading to the consideration of using non-parametric statistical analysis techniques in this study.

Table 1. Data normality test results with Komogorov-Smirnov and Shapiro-Wilk

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PreC	.177	73	.000	.958	73	.015
PostC	.167	73	.000	.966	73	.046
PreE	.181	73	.000	.947	73	.004
PostE	.157	73	.000	.957	73	.014

a. Lilliefors Significance Correction



(a) (b)

(c) (d)

Figure 1. Normal Q-Q plot of: (a) control group ptetest; (b) control group posttest; (c) experiment group pretest; and (d) experiment group posttest.

In Figure 1, although the Normal Q-Q Plot shows that the data from the four groups (control and experimental groups in the pretest and posttest) tend to follow a normal distribution, the normality test results conducted previously indicate very low significance values ($p < 0.05$) in all groups. A p-value less than 0.05 in the Kolmogorov-Smirnov and Shapiro-Wilk tests indicates that the data are not normally distributed. Therefore, to analyze the data more accurately, non-parametric statistical methods will be used. Non-parametric statistics do not require data to follow a normal distribution and are more appropriate when data do not meet the assumptions of normal distribution. Thus, data analysis will be conducted using a non-parametric approach to obtain valid and reliable results.

3.2. Descriptive statistics of problem-solving skill scores

The data shown in Table 2 present descriptive statistics for the control group and the experimental group on the pretest and posttest. In the control group, the pretest scores (PreC) ranged from 28 to 69, with a mean of 47.86 and a standard deviation of 9.62. This indicates considerable variation in students' problem-solving abilities before the treatment was administered. After the treatment, the posttest scores (PostC) showed a significant increase, with a minimum score of 49 and a maximum score of 96, an average of 69.10, and a standard deviation of 9.75, indicating that the control group students showed an improvement in their abilities after participating in the learning process, although the average posttest score was still lower than that of the experimental group. In terms of distribution, the pretest and posttest data of the control group showed a small positive skewness on the posttest (0.170), indicating a slight tendency toward a right-skewed distribution, and negative kurtosis, indicating that the data distribution was slightly flatter than a normal distribution.

Meanwhile, in the experimental group, the pretest data (PreE) showed a minimum value of 28 and a maximum of 67, with an average of 47.77 and a standard deviation of 9.30, which was very similar to the control group in the pretest. After the implementation of the Problem-Based Learning model assisted by PhET simulation, the experimental group showed a greater improvement on the posttest (PostE), with a minimum value of 61 and a maximum of 100, and a mean of 80.70 and a standard deviation of 9.42. This increase in the mean indicates that the implementation of the learning model had a positive impact on students' problem-solving abilities. The data distribution in the experimental group tended to be symmetrical, with a skewness value close to zero and a slightly flatter negative kurtosis than the normal distribution, indicating that the data distribution did not show significant deviation from normality. However, we still use the results of the normality test that we have conducted.

Overall, the data show that both the control and experimental groups experienced a significant improvement in problem-solving ability, with the experimental group showing a greater improvement. Although the data distribution in both groups is not completely normal, both have relatively symmetrical distribution characteristics, indicating that non-parametric statistical techniques can be used for further analysis.

Table 2. Descriptive statistics of problem-solving skill scores of the pretest and posttest data

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
PreC	73	28.00	69.00	47.86	9.62	92.45	.025	.281	-.442	.555
PostC	73	49.00	96.00	69.10	9.75	95.06	.170	.281	-.157	.555
PreE	73	28.00	67.00	47.77	9.30	86.49	-.026	.281	-.388	.555
PostE	73	61.00	100.00	80.70	9.42	88.74	-.045	.281	-.444	.555

This data description provides an overview of the improvement in students' problem-solving skills after the implementation of the PhET simulation-assisted Problem-Based Learning model. Overall, there was a significant improvement in problem-solving skills in both the control and experimental groups, with the experimental group showing a greater improvement. However, despite the improvement in both groups, this data only provides an overview of the differences between the pretest and posttest scores. To gain a deeper understanding of the influence of the learning model on problem-solving skills, further analysis is needed using non-parametric statistical tests. Non-parametric statistical tests will be used to test whether the differences observed between the pretest and posttest scores in each group are significant, given that the data are not normally distributed. The test used is the Mann-Whitney U test. Using this approach, it is hoped that stronger evidence can be obtained regarding the effect of the PhET simulation-assisted Problem-Based Learning model on improving students' problem-solving skills.

3.3. Differences in problem-solving skill scores before treatment

Table 3 shows the use of the Mann-Whitney U Test, which is a non-parametric statistical test used to compare two groups that are not normally distributed. The test results show that the Mann-Whitney U value is 2622.500, with a Wilcoxon W of 5323.500 and a Z value of -0.168. The significance value (Asymp. Sig.) is 0.866, which is greater than the significance level of 0.05. This means that there is no significant difference between the experimental group and the control group in the pretest scores.

It is important to conduct a difference test before treatment to ensure that both groups, namely the experimental and control groups, have equal abilities at the outset (before treatment is administered). In other words, this test aims to ensure that the differences observed after treatment are not caused by differences in initial abilities between the two groups. If the pretest scores of the two groups are not significantly different, then we can be more confident that the differences in posttest results are due to the treatment received by each group, not due to differences in their initial abilities. The results of this difference test indicate that the two groups have similar initial abilities in terms of problem-solving skills, so further analysis of the effect of the treatment can be conducted with the confidence that both groups started from the same point.

Table 3. Mann-Whitney U test results for problem-solving skill scores for pretest

Test Statistics[a]

	PreScore
Mann-Whitney U	2622.500
Wilcoxon W	5323.500
Z	-.168
Asymp. Sig. (2-tailed)	.866

a. Grouping Variable: GroupPre

3.4. Differences in problem-solving skill scores after treatment

The results of the posttest score comparison in Table 4 show the use of the Mann-Whitney U Test to compare the two groups after treatment. In this test, the Mann-Whitney U value obtained was 1126.500, with a Wilcoxon W of 3827.500 and a Z value of -6.044. The Asympt. Sig. (2-tailed) is 0.000, which is less than 0.05, indicating a highly significant difference between the experimental group and the control group in the posttest scores.

These results indicate that the treatment given to both groups produced significant differences in their problem-solving abilities after learning. The experimental group, which used the PhET simulation-assisted Problem-Based Learning model, showed greater improvement compared to the control group. This improvement can be attributed to differences in the learning methods applied, where the PhET simulation-assisted PBL model provided a more interactive and in-depth learning experience compared to the conventional method applied to the control group.

The significance found in this posttest is very important because it provides evidence that the differences in results between the two groups did not occur by chance. Thus, it can be concluded that the PhET simulation-assisted Problem-Based Learning model has a significant effect on improving students' problem-solving skills. The results of this test reinforce the argument that the application of this learning model has a greater positive impact on the experimental group, as reflected in the higher posttest scores compared to the control group.

Table 4. Mann-Whitney U test results for problem-solving skill scores for posttest

Test Statistics

	PostScore
Mann-Whitney U	1126.500
Wilcoxon W	3827.500
Z	-6.044
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: GroupPost

3.5. Normalized gain and effect size calculations

The results of N-gain and Cohen's d analysis in the control and experimental groups provide a clear picture of the effect of the learning model applied on the improvement of students' problem-solving skills (see Table 5). The N-gain value for the control group was 0.41, indicating a moderate increase in problem-solving ability after treatment. Although there was an improvement, this N-gain value indicates that the conventional learning method used in the control group only had a limited impact on the improvement of students' skills. In contrast, the experimental group that used the PhET simulation-assisted Problem-Based Learning model showed a higher N-gain value of 0.630, indicating a more significant improvement in problem-solving skills, ranging from moderate to high. This shows that the application of the PhET simulation-assisted learning model is more effective in promoting student skill improvement than conventional learning.

Additionally, the Cohen's d value for the control group was 2.19, indicating a very large effect despite the use of conventional learning methods. However, the Cohen's d value for the experimental group, which reached 3.52, was significantly higher, indicating a very large effect and showing that the PhET simulation-assisted learning model has a much stronger influence in enhancing students' problem-solving skills. Based on these results, it can be concluded that the PhET simulation-assisted Problem-Based Learning model has a greater and more significant impact on improving students' skills compared to conventional learning, both in terms of relative improvement (N-gain) and the magnitude of the effect (Cohen's d).

Table 5. Normalized gain and effect size calculations

	Control Group	Experiment Group
N-gain	0.41	0.63
d	2.19	3.52

Problem-Based Learning (PBL) can improve students' problem-solving skills because of its student-centered approach and emphasis on solving real-world problems (Anugraheni et al., 2025; Lee et al., 2023; Tanna et al., 2022; Carder et al., 2001; Pinto, 2022). In PBL, students are presented with complex and unstructured problems, which encourage them to think critically and creatively. This approach encourages students to actively seek information, work together in groups, and connect the concepts they learn to real-world situations (Andayani & Gunawan, 2025; Putri et al., 2025). In this research, students were not only taught certain theories, but they were also encouraged to apply that knowledge to solve problems, which makes learning more relevant and interesting.

Within the pedagogical framework, PBL supports the constructivist learning theory developed by Piaget and Vygotsky (Yildiz, 2025; Zhang, 2022), which emphasizes that the most effective learning occurs when students actively interact with their environment and build understanding based on direct experience. Through PBL, students are expected to develop their problem-solving skills in a more natural way, as they are given the opportunity to design solutions independently, test their ideas, and then reflect on the process (Gumisirizah et al., 2023; Gumisirizah et al., 2024; Huzii et al., 2021). This process facilitates the strengthening of higher-order thinking skills, such as analysis, synthesis, and evaluation, which are essential in solving more complex problems.

PhET, or Physics Education Technology, played an important role in improving students' problem-solving skills by providing interactive simulations that visualized abstract physics and mathematics concepts. These results are consistent with several previous studies (e.g., Susilawati et al., 2022; Mashami et al., 2023; Yani & Widiyatmoko, 2023). By using PhET simulations, students could directly see the impact of their decisions in a controlled context, which facilitated a better understanding of theories and principles. In learning, students in the experimental class appeared to be more active and enthusiastic compared to the control class, especially when conducting virtual experiments with PhET. These results are in line with the results of Banda & Nzabahimana's (2023) research, which shows that physics learning using PhET can increase student motivation so that students are more active in learning. These simulations allowed students to conduct virtual experiments that would have been difficult to perform in a physical classroom, and accelerated the learning process by providing opportunities to repeat experiments without time or cost constraints.

In the context of PBL, PhET provided highly effective resources to help students apply the theories they had learned in more concrete situations. Through simulation experiments, students could test hypotheses, explore different variables, and devise solutions to given problems. In the learning process, students can explore things they do not yet understand by conducting virtual experiments. This helps them understand abstract concepts in a more concrete way (Chinaka, 2021; Salame & Makki, 2021; Rizkianto et al., 2024). This practical experience deepened their understanding of the concepts taught and strengthened their problem-solving skills. Furthermore, PhET simulations integrated technology into learning, which was increasingly important in that digital age (Diab et al., 2024). This technology allowed students to learn more deeply, overcome conceptual difficulties visually, and accelerate their understanding of difficult topics.

Although this study provides useful insights into the influence of the PhET simulation-assisted Problem-Based Learning model on students' problem-solving abilities, there are several limitations that need to be considered. One of them is the limitation in terms of the generalizability of the research results. This study only involved one school and two groups with a limited sample size of 73 students per group. This may limit the ability to generalize these findings to a wider population, such as other schools with different characteristics or groups of students with varying academic backgrounds. In addition, although the PhET simulation-assisted learning model showed significant results in improving problem-solving skills, this study did not explore in depth other factors that may influence learning outcomes, such as student motivation, parental involvement, or existing learning facility support.

Another limitation is the use of non-parametric statistical tests based on non-normally distributed data, which, although appropriate for these conditions, may not provide as comprehensive a picture as if the data followed a normal distribution. Therefore, further research using more varied experimental designs and larger, more diverse samples would provide stronger and more generalizable evidence.

Future research could focus on developing and testing other technology-assisted learning models, as well as examining more specific factors that influence the success of this learning model. Further research could expand the variables studied, such as by measuring student motivation, level of engagement in learning, or the role of teachers in implementing this model. Additionally, to strengthen the findings, future research could involve more schools with diverse student characteristics and use more complex statistical analysis techniques to gain a deeper understanding of the effectiveness of technology-assisted Problem-Based Learning models in various learning contexts.

4. CONCLUSION

This study investigated the impact of the Problem-Based Learning (PBL) model assisted by PhET simulation on students' problem-solving abilities. The findings revealed that both the experimental and control groups experienced significant improvements in their problem-solving skills, but the experimental group, which utilized the PhET simulation-assisted PBL model, showed more substantial progress. The results indicate that the application of this innovative learning model was more effective in enhancing students' problem-solving capabilities compared to conventional methods. The study also confirmed that the PBL model with PhET simulations offered a more engaging and interactive learning experience, contributing to the higher gains observed in the experimental group. These findings suggest that integrating technology-assisted learning approaches like PhET simulations into problem-based learning can significantly enhance students' skills, providing valuable insights for future educational practices. However, further research with larger, more diverse samples and additional variables is recommended to deepen the understanding of the model's effectiveness in different learning environments and to explore other factors that may influence learning outcomes.

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There is no conflict of interest in this study.

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ETHICAL STATEMENT

This study has obtained approval from all research subjects through written statements.

AI USE STATEMENT

This article was written without using Generative Artificial Intelligence. AI was used to correct grammar using Grammarly.

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