Jurnal Teknologi Pendidikan, December 2024, 26 (3), 960-970
DOI: http://dx.doi.org/10.21009/JTP2001.6
p-ISSN: 1411-2744 e-ISSN: 2620-3081
Accredited by Directorate General of Strengthening for Research and Development
Available online at http://journal.unj.ac.id/unj/index.php/jtp

Utilization, Simulation and Learning: The Virtual Laboratory Learning Media PhET for Outcomes Learning

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Received :: November 14, 2024
Revised : November 23, 2024
Accepted : December 30, 2024

Abstract
This study examines the effectiveness of PhET simulations in improving physics learning outcomes for Class XII IPS 4 students at SMA Negeri 1 Beduai. Physics is often perceived as a challenging subject due to its abstract concepts, which are difficult to visualize and understand using traditional teaching methods. Interactive digital tools like PhET simulations offer a promising approach to help students grasp complex concepts more easily. Using a quasi-experimental design, the study compares an experimental group, which used PhET simulations, with a control group that followed traditional teaching methods. The study analyzed pre-test and post-test scores to assess the impact of the simulations on student learning. The results show a significant improvement in the experimental group's performance, with post-test scores noticeably higher than pre-test scores. Statistical analysis, including paired sample t-tests, confirmed that PhET simulations significantly enhanced students' problem-solving skills and understanding of physics concepts ($t = -17.329$, $p < 0.05$). These findings highlight the effectiveness of PhET simulations, combined with an inquiry-based learning approach, in fostering a deeper understanding of abstract physics concepts and promoting critical thinking. Overall, this study supports the use of PhET simulations as a practical and accessible tool for improving physics education, even in schools with limited technological resources.

Keywords: Physics, Learning Outcomes, Technology Integration, PhET Learning Media

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How to Cite: Warneri, W., Salam, U., Putri, W. A., Imandari, R. Z., Pratiwi, R. D., & Chairunnisa, T. (2024). Utilization, Simulation and Learning: The Virtual Laboratory Learning Media PhET for Outcomes Learning. *JTP - Jurnal Teknologi Pendidikan*, *26*(3), 960–970. https://doi.org/10.21009/jtp.v26i3.49832

INTRODUCTION

PhET simulations are highly effective in supporting physics learning, offering an advantage over other digital tools. These simulations use dynamic graphics to help students visualize abstract concepts, enabling independent learning through an inquiry-based approach that fosters cognitive development. Unlike more expensive technologies like Virtual Reality (VR) or Augmented Reality (AR), PhET is offline-accessible, making it practical and affordable. While AR holds educational promise (Cipresso et al., 2018), research supports PhET's effectiveness in teaching physics. Sari et al., (2019) found that combining PhET with an inquiry model improved students' understanding of physics concepts. Studies by Arifin et al., (2022); Hasyim et al., (2020); Putranta et al., (2019) also show that PhET enhances learning outcomes and critical thinking. Mahtari et al. (2020)

demonstrated that PhET, with guided questions, improves learning results. The integration of the CCL (Collaborative Creativity Learning) model with PhET has been shown to enhance students' scientific creativity (Astutik & Prahani, 2018). This combination of virtual and PhET simulations optimizes student learning outcomes through practical engagement. As Rahmawati et al. (2020) note, physics learning should be student-centered, with students actively participating in practical activities. Therefore, PhET simulations provide an accessible and effective tool for enhancing physics education, aligning with modern teaching strategies.

Physics is a challenging subject due to abstract concepts like motion, energy, electricity, and magnetism, which are hard to visualize with traditional methods like lectures or textbooks. This affects students' ability to apply these concepts in real-world situations. A similar challenge exists in teaching English to young learners, as children acquire languages differently from adults (Sofian & Anggraeni, 2021). To address these issues, teaching strategies should focus on enhancing understanding and critical thinking. The Problem-Based Learning (PBL) model, combined with Augmented Reality (AR), has been shown to improve student motivation and learning outcomes by encouraging active engagement and critical thinking (Febrianto & Aeni, 2024). Interactive tools like PhET simulations offer an effective way to deepen understanding and improve problem-solving in physics (Rahmawati et al., 2020). By incorporating such strategies, teachers can help students overcome challenges and develop skills crucial for academics and real-world situations.

In today's digital era, integrating technology into education is crucial. One effective way to support physics learning is through digital tools like interactive simulations, e-books, and virtual labs. These resources help students grasp abstract concepts more easily. One such tool is PhET Simulations, developed by the University of Colorado Boulder. PhET offers virtual labs where students can manipulate variables—such as mass, force, and voltage—and observe real-time effects on physical systems. According to Faizah et al. (2023; Tuhusula et al. (2020), PhET is widely used across educational levels, from elementary schools to universities, for science and math topics. The simulations are interactive, allowing students to connect real-world phenomena with underlying scientific principles while providing immediate feedback and creative workspaces. Haryadi & Pujiastuti (2020) note that this approach helps students visualize complex concepts and learn hands-on, without needing costly physical labs. Additionally, PhET's user-friendly, offline capabilities make it ideal for flexible learning environments, as highlighted by (Andayani et al., 2024). Its interactivity and accessibility foster deeper, independent learning, essential for mastering abstract physics concepts (Rahmawati et al., 2020).

PhET simulations are an effective tool for making abstract physics concepts more tangible. Research by Rahmawati et al. (2020) demonstrates that PhET simulations improve students' understanding of physics, particularly when combined with inquiry-based learning (IBL). IBL encourages students to explore, experiment, and solve problems independently, fostering deeper learning and critical thinking. Pinilih et al. (2024) further highlight that digital tools like PhET increase student engagement, leading to better learning outcomes. In addition, Astutik & Prahani (2018) explains that integrating collaborative learning models, such as the CCL model, enhances scientific creativity by encouraging positive dependence and leveraging cognitive psychology principles. This model fosters not only engagement but also the development of critical thinking and creativity, which are essential for academic success and real-world problem-solving. Thus, incorporating PhET simulations into physics education not only promotes exploration and critical thinking but also nurtures creativity, preparing students for future challenges.

When combined with Problem-Based Learning (PBL), PhET simulations help students apply theoretical knowledge to solve real-life problems. PBL is a student-centered approach that emphasizes learning through the investigation of real-world issues. As Mige et al. (2023) explain, PBL builds important cognitive and social skills, such as critical thinking, teamwork, communication, and problem-solving. This approach not only improves academic performance but also prepares students for collaborative work in the modern workforce. Moreover, the flexibility of PhET simulations aligns well with the demands of today's education system, where creativity and critical thinking are essential for success in the Fourth Industrial Revolution (4IR). Thus, combining PBL with PhET simulations helps students develop both academic and life skills that are crucial for their future careers.

The Covid-19 pandemic accelerated the digital transformation of education, highlighting the need for digital literacy and online learning platforms. The COVID-19 pandemic through online learning has an impact on all parties, be it teachers, students, and even parents who now have to be more actively involved in the learning process. Not only active, all parties, especially students, are required to be independent in every learning process (Azis et al., 2024)."According to Muzayyin & Handayani (2023), access to digital tools and digital literacy skills became essential for effective learning during the pandemic. The shift to online and hybrid learning environments highlighted the demand for more flexible, accessible, and interactive resources. PhET simulations proved to be a valuable tool during this period, providing students with meaningful learning experiences even in remote settings. By using technology, teachers can overcome the limitations of traditional teaching methods and ensure that students continue to learn complex concepts despite the challenges posed by the pandemic. PhET plays a key role in supporting continuous education and aligns with the growing emphasis on self-directed learning and digital skills in modern education.

Interactive multimedia, such as PhET simulations, represents a major advancement in educational technology. These tools not only help convey content but also promote a dynamic interaction between the student and the material, which improves engagement and retention. Purba et al. (2023) explain that this interactivity allows students to experiment with the material, deepening their understanding. Moreover, these systems track student progress in real time, offering valuable insights into individual learning paths. As Purba et al. (2023) point out, the system functions like a tutor, providing personalized feedback that enriches the learning experience. By promoting autonomy and critical thinking, these systems foster independent learning, which is crucial for academic growth in today's educational landscape.

The importance of integrating digital media into education is further emphasized by Anissi & Darmansyah (2024), who argue that interactive multimedia significantly improves learning outcomes, especially in challenging subjects like physics. When combined with modern teaching strategies like Problem-Based Learning (PBL), interactive media can lead to more effective learning than traditional methods. This combination allows students to engage with the content more actively and enhances their ability to solve real-world problems. As Mahtari et al. (2020) note, PhET simulations provide a meaningful and accessible way for students to learn and apply complex concepts. By allowing students to manipulate variables and observe real-time effects, PhET not only improves understanding but also promotes critical thinking and problem-solving—skills essential for mastering physics.

The present study aims to investigate the effectiveness of PhET Simulations in improving students' learning outcomes in physics, particularly in class XII IPS 4 at SMAN 1 Beiduai. By incorporating PhET and other digital technologies into the classroom, this study seeks to identify innovative teaching strategies that can significantly improve students' understanding of complex physics concepts while enhancing their problem-solving and critical thinking skills. This is especially relevant as there is an increasing need for student-centered learning models that emphasize active engagement and deeper understanding. As Mige et al. (2023) highlight, integrating technology with these learning models is crucial for preparing students for the challenges and opportunities in the modern world. The results of this study will contribute to the development of more effective teaching methods, helping educators use digital tools to create richer learning experiences for students.

METHODS

This research utilizes a quantitative approach with a quasi-experimental design, specifically the one-group pre-test post-test design. The purpose of the study is to assess the impact of using PhET Simulation Virtual Laboratory media on improving students' physics learning outcomes. The experimental group, consisting of 33 students from Class XII IPS 4 at SMA Negeri 1 Beduai, was selected using a purposive random sampling technique. The group received treatment in the form of PhET simulations integrated into their physics lessons. The effectiveness of the treatment was measured by administering a pre-test before the intervention and a post-test after the intervention. Each session of the study included both a pre-test and a post-test to evaluate changes in students' learning outcomes.

The research followed a structured process, which included the preparation of instruments, literature review, curriculum analysis, pre-test implementation, treatment (using PhET simulation), post-test administration, and post-treatment observation. The data for this research were collected from both quantitative and qualitative sources. The quantitative data consisted of students' test scores from the pre-test and post-test, and these were analyzed to determine the improvement in students' learning outcomes. The students' engagement with and perceptions of the PhET simulations were also gathered through surveys to assess their interactions with the virtual laboratory. Additionally, qualitative data were collected through classroom observations, using an observation sheet to monitor the teacher's implementation of the PhET-based learning activities and the use of the virtual laboratory in the classroom.

The population for the study included all students in Class XII IPS 4, with the sample being determined by the purposive sampling technique. The research instruments—pre-test, post-test, and observation sheets—underwent validity and reliability testing. Content validity was ensured by consulting with subject matter experts, while reliability was assessed using the split-half method. The difficulty level and discrimination power of the test items were analyzed to ensure the quality of the assessments. Data were analyzed using gain and normalized gain scores to measure the effectiveness of the PhET simulations in improving student learning outcomes. The analysis also focused on examining the implementation of the learning media based on observations of the teacher's activities in applying the virtual laboratory.

The type of debonding used in this research is quantitative debonding with a quasi-experimental design. Research uses the One Group Pretest-Posttest Design (single group design with pretes-postest design). The use of PhET Simulation virtual laboratory learning media to improve students' physics learning outcomes is described as follows:

Tabel 1. Quasi-experimental design

O1	X	O2

O1 : Pre-test results (before treatment)
X : Treatment phase (in this study, the use of PhET Simulation Virtual Laboratory as a learning media in physics)
O2 : Post-test results (after treatment)

This design was chosen to evaluate the impact of PhET simulations on students' understanding of physics, particularly in the context of Ohm's Law. The study first administered a pre-test to assess the students' initial understanding of the material, followed by the treatment phase where students were taught using PhET simulations. After the treatment, a post-test was administered to assess changes in students' learning outcomes.

The data were analyzed using SPSS Software 26 to ensure accuracy and reliability. t-tests were performed to determine whether there were significant differences between pre-test and post-test scores, using paired samples from the same group of students. The results of the study are expected to provide valuable insights into the effectiveness of using virtual laboratory media, specifically the PhET simulations, in enhancing student learning outcomes in physics. This research aims to contribute to the broader understanding of how interactive simulations can improve the learning process, especially in the context of complex physics concepts like Ohm's Law.

RESULTS & DISCUSSION

The results of this study demonstrate a significant improvement in the physics learning outcomes of Class XII IPS 4 students at SMA Negeri 1 Beduai who used the PhET Simulation Virtual Laboratory, compared to those who were taught using conventional methods. The experimental group, which utilized the virtual laboratory media, showed a higher level of performance on the posttest, indicating that the PhET simulations positively influenced students' problem-solving abilities in physics. In contrast, the control group, which used traditional teaching methods, exhibited more modest improvements in their posttest scores.

To ensure the validity of the data, normality testing and an equivalence test were conducted prior to the analysis. The results confirmed that both groups followed a normal distribution and were balanced before the intervention. These statistical tests provide strong evidence supporting the effectiveness of the PhET Simulation Virtual Laboratory in enhancing students' learning outcomes in physics. The detailed findings, including the means and distribution of pretest and posttest scores for both groups, are presented in Table 1.

Table 1. Distribution of Pretest and Posttest Scores

No	Perolehan Pretest	Pretest (f)	Posttest (f)	Pretest (%)	Posttest (%)
1	40 - 50	5	3	31%	19%
2	51 - 60	5	2	31%	13%
3	61 - 70	4	4	25%	25%
4	71 - 80	2	5	13%	31%
5	81 - 90	0	2	0%	13%
	Total			100%	100%

The table above shows the distribution of pretest and posttest scores for both the experimental and control groups. In the pretest, most students in both groups were clustered in the lower score ranges (40-60). However, after the intervention, a noticeable shift occurred, particularly in the experimental group, where more students scored higher in the posttest (71-80 and 81-90 ranges). Specifically, 31% of the experimental group scored in the 71-80 range, and 13% scored in the 81-90 range, reflecting significant improvement. In contrast, the control group demonstrated more modest improvements, with 31% scoring in the 71-80 range and only 13% in the 81-90 range.

These results suggest that the PhET Simulation Virtual Laboratory had a more substantial impact on the experimental group's learning outcomes, as evidenced by the higher posttest scores in the higher ranges. In comparison, the control group showed less marked improvement, which supports the effectiveness of the virtual laboratory in enhancing students' understanding and problem-solving skills in physics.

The data obtained from this study were analyzed using descriptive statistics to summarize the students' learning outcomes. Descriptive analysis was performed to provide an overview of the pretest and posttest results. The following tables present the summary of the students' scores before and after the intervention.

Table 2. Descriptive Statistics of Students' Physics Learning Results

Statistik	Pre Test	Post Test
N	33	33
Average	53.52	76.33
Maximum score	65	85
Minimum score	40	65
Standart Deiviasi	6.88	4.25
Varians	47.44	18.10

The descriptive statistics indicate that the mean score of the pretest was 53.52, which suggests that students had a moderate understanding of the material before the intervention. After using the PhET Simulation Virtual Laboratory, the mean score increased significantly to 76.33, indicating substantial improvement. The reduction in standard deviation from 6.88 in the pretest to 4.25 in the posttest indicates a more consistent performance in the posttest, suggesting that the virtual laboratory helped reduce variability in students' learning outcomes.

Hypothesis Testing

The hypothesis was tested using a paired sample t-test. The null hypothesis (Ho) and alternative hypothesis (Ha) were as follows:
Ho: There is no influence of the PhET Simulation virtual laboratory learning media on improving the physics learning outcomes of Class XII IPS 4 students at SMA Negeri 1 Beduai.
Ha: There is an influence of the PhET Simulation virtual laboratory learning media on improving the physics learning outcomes of Class XII IPS 4 students at SMA Negeri 1 Beduai.

Table 3. Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pre Test	53.52	33	6.888	1.199
	Post Test	76.33	33	4.255	.741

Table 4. Statistical Results from the Paired t test Sample Test

		Paired Differences					T	df	Sig.(2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Pre Test - Post Test	-22.818	7.564	1.317	-25.500	-20.136	-17.329	32	.000

The paired sample t-test revealed a significant difference between the pretest and posttest scores ($t = -17.329$, $p < 0.05$). The negative t-value indicates that the posttest scores were significantly higher than the pretest scores, which shows that the PhET Simulation Virtual Laboratory led to a substantial improvement in students' performance. The p-value of 0.000, which is less than 0.05, indicates that this difference is statistically significant. Therefore, we reject the null hypothesis and conclude that the PhET Simulation has a positive and significant effect on students' physics learning outcomes.

Discussion

Physics is often perceived as a challenging subject, primarily due to its abstract concepts, such as motion, energy, electricity, and magnetism. These topics are notoriously difficult to visualize and comprehend through traditional teaching methods, such as lectures or textbook readings. This challenge is not exclusive to physics; a similar difficulty is observed in other complex disciplines, such as language acquisition in young children, who learn languages differently from adults (Sofian & Anggraeni, 2021). Given these challenges, teaching strategies must evolve to enhance students' understanding and foster critical thinking

The results of this study align with the growing body of research suggesting that conventional teaching methods may not be sufficient for helping students grasp complex scientific concepts. Our findings demonstrate that PhET simulations significantly enhance students' understanding by enabling them to visualize abstract concepts interactively. By providing dynamic, real-time graphics, PhET simulations offer students a hands-on approach that fosters deeper comprehension and critical thinking. These simulations allow students to manipulate variables such as mass, force, and voltage, helping them observe the real-time effects on physical systems. This interactive engagement, as highlighted by Cipresso et al. (2018), not only supports conceptual understanding but also encourages independent learning—a key factor in mastering difficult topics. In contrast to more expensive technologies, such as Virtual Reality (VR) or Augmented Reality (AR), PhET is affordable and offline-accessible, making it a practical solution for classrooms with varying levels of technological resources.

Our study shows that the experimental group, which used PhET simulations, demonstrated significant improvement in post-test scores. This aligns with the findings of Rizaldi et al. (2020), who assert that PhET simulations enhance students' ability to visualize abstract concepts and engage in active learning. Similarly, studies by Arifin et al. (2022); Hasyim et al. (2020) also support the conclusion that PhET simulations not only improve learning outcomes but also stimulate critical thinking. In particular, PhET simulations appear to be particularly effective in helping students understand challenging topics, such as electricity and energy.

In addition to the benefits of PhET simulations, the importance of inquiry-based learning (IBL) in physics education cannot be overstated. Research by Sari et al. (2019) demonstrates that combining PhET simulations with IBL models enhances students' understanding of physics concepts. Inquiry-based learning encourages students to explore, experiment, and solve problems independently, promoting deeper learning and fostering critical thinking. As Rahmawati et al. (2020) note, PhET simulations, when paired with an inquiry-driven approach, create a dynamic and engaging learning environment that significantly improves students' grasp of complex topics. This approach not only supports understanding but also aligns well with the CCL (Collaborative Creativity Learning) model, which fosters scientific creativity and problem-solving (Astutik & Prahani, 2018).

Furthermore, studies by Almadrones & Tadifa, (2024); Hasyim et al. (2020) reinforce the effectiveness of PhET simulations in enhancing students' conceptual understanding and analytical skills. Our research findings confirm that students who used PhET simulations demonstrated improved problem-solving abilities, suggesting that these interactive tools contribute to both conceptual clarity and the development of critical thinking skills.

The statistical significance of the improvement in learning outcomes, as indicated by the t-test results ($t = -17.329$, $p < 0.05$), further strengthens the case for PhET simulations as an effective educational tool. These results corroborate previous studies, such as those by Nefrita, (2019); Ramadhan et al. (2019), which suggest that PhET simulations enhance student engagement, improve the comprehension of abstract scientific concepts, and lead to better academic performance.

While the benefits of PhET simulations are evident, it is important to acknowledge the challenges of integrating these tools into classrooms, particularly in regions with limited technological resources. As Rizaldi et al. (2020) point out, access to computers remains a significant barrier for many schools. Nevertheless, the findings of this study underscore the potential of PhET simulations to significantly improve learning outcomes when they are accessible. Despite the challenges, this study suggests that PhET simulations should be regarded as an essential tool in enhancing physics education, especially in schools that have adequate technological infrastructure.

In today's digital age, integrating technology into education has become crucial. As Rahmawati et al. (2020) emphasize, "PhET simulations provide a dynamic, inquiry-driven learning environment that enhances students' conceptual understanding, critical thinking, and problem-solving skills." This flexibility, combined with PhET's offline capabilities, makes it an ideal tool for fostering independent learning in various educational settings, including those with limited resources. The importance of interactive digital media in education is also highlighted by Anissi & Darmansyah (2024), who argue that such tools significantly improve learning outcomes, particularly in challenging subjects like physics.

The COVID-19 pandemic accelerated the digital transformation of education, underscoring the importance of digital literacy and online learning platforms. Muzayyin & Handayani (2023) note that during the pandemic, access to digital tools and digital literacy became essential for effective learning. The shift to online and hybrid learning environments has increased the demand for flexible, accessible, and interactive learning resources. During this period, PhET simulations proved invaluable, providing students with meaningful learning experiences even in remote settings. By utilizing technology, educators were able to overcome the limitations of traditional teaching methods, ensuring that students could continue to learn complex concepts despite the challenges posed by the pandemic.

Interactive multimedia tools, such as PhET simulations, represent a significant advancement in educational technology. These tools promote dynamic interaction between the student and the material, improving engagement and retention. As Purba et al. (2023) explain, this interactivity allows students to experiment with the material, thereby deepening their understanding. Moreover, PhET simulations track student progress in real time, offering valuable insights into individual learning paths. By encouraging autonomy and critical thinking, these systems foster independent learning, which is essential for academic success in today's educational landscape.

In conclusion, the findings of this study underscore the importance of integrating digital tools, such as PhET simulations, into physics education. These simulations create a dynamic, inquiry-driven learning environment that enhances students' conceptual understanding, critical thinking, and problem-solving abilities. As the educational landscape continues to evolve, tools like PhET simulations will play an increasingly crucial role in helping students master abstract scientific concepts and develop the essential skills required for the future.

CONCLUSION

The findings of this study highlight the significant impact of PhET simulations on improving students' learning outcomes in physics, particularly in Class XII IPS 4 at SMA Negeri 1 Beduai. Students who used PhET simulations demonstrated higher posttest scores and enhanced problem-solving abilities compared to those taught using traditional methods. This supports the effectiveness of interactive tools in making abstract concepts more accessible and promoting critical thinking. By combining PhET simulations with inquiry-based learning (IBL), students are encouraged to explore and experiment, fostering a deeper understanding of complex scientific topics. Despite challenges in technological access, the study confirms that PhET simulations are an affordable and powerful tool for enhancing physics education, helping students visualize key concepts and develop essential skills like creativity, independence, and problem-solving. As educational approaches continue to evolve, integrating digital tools like PhET will play an increasingly crucial role in preparing students for future academic and professional challenges.

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