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Digitization of Learning Through Virtual Laboratory in Assessing Students' Science Process Skills on Mechanical Wave Material

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Abstract

This study explores the impact of utilizing the PhET virtual laboratory on the development of science process skills among students. Conducted with a repeated treatment design (one group pretest-posttest design), the research involved 30 eleventh-grade science students from MA Bahrul Ulum Jombang. Throughout the study, students engaged with mechanical wave topics using the PhET virtual simulations. Their science process skills were meticulously evaluated through various scientific approaches including problem formulation, hypothesis development, identification of variables, data interpretation, and the ability to draw logical conclusions. The results revealed a marked improvement in these skills following the intervention with the virtual laboratory. Specifically, students demonstrated enhanced abilities in forming coherent hypotheses, accurately identifying relevant variables, and effectively interpreting complex data sets. Moreover, their skills in synthesizing information to formulate valid conclusions were significantly bolstered. The use of the PhET virtual laboratory not only fostered a deeper understanding of mechanical wave concepts but also facilitated a more interactive and engaging learning environment. These findings advocate for the broader integration of such technological tools in science education, emphasizing their role in enriching students' learning experiences and advancing their analytical and scientific thinking skills.

Keywords: Virtual laboratory, science process skill, mechanical waves, PhET simulation

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INTRODUCTION

Physics, as a part of natural sciences in schools, plays a crucial role in explaining various natural phenomena in daily life through theories, concepts, and physical laws. Understanding physics means grasping nature and its concepts, which are fundamental to several other branches of science. Besides mastering the products of physics, it is also vital to comprehend how these products are derived through the scientific process and the development of students' scientific attitudes (Astuti, 2012). Physics education not only emphasizes the cognitive domain but also the psychomotor and affective aspects (Prihatiningtyas, 2018). Psychomotor skills are significant as they aid students in better understanding physics material (Astuti & Handayani, 2018).

As a discipline that highlights experimentation, physics aims to uncover patterns and principles that link various natural phenomena (Hasibuan & Abidin, 2019). This activity involves experimentation, measurement, and the mathematical presentation of data based on general principles that assist students in transforming abstract concepts into more tangible understandings (Handayani, 2018). Although conducting experiments requires precision, is time-consuming, and potentially results in significant errors, the field of physics is not limited to the memorization of theories or formulas (Astuti & Handayani, 2018). Instead, understanding physics involves a deep comprehension of various concepts (Saputra et al., 2020). Therefore, the development of media and strategies to support physics experiments is necessary.

Technological advancements compel the educational field to quickly adapt to changes in the learning environment. In this digital era, technological innovations provide significant positive benefits in supporting the learning process. Technology can facilitate the implementation of teaching and learning activities in education (Akbar et al., 2023). Various learning media such as ebooks, PowerPoint, interactive videos, animations, and virtual simulations can be developed using technology to enhance learning efficiency in schools (Ningsih & Islami, 2023). One of the main implications of technological progress in education is the potential to conduct experiments or simulations through virtual laboratories.

A virtual laboratory is an unconventional experimental facility where observations and trials are conducted through computer software. All necessary tools are available through this software, eliminating the need for physical infrastructure such as laboratory buildings or traditional equipment (Ardius, 2019). The main advantage of virtual laboratories is their capability to perform experiments that are difficult or even impossible in conventional labs. Moreover, virtual laboratories offer high flexibility as they can be accessed anytime and anywhere, unbound by spatial and temporal limitations (Wibawanto, 2020). Manual experiments often require time and precision in data collection, while manual analysis tends to be slow and inefficient. Therefore, virtual laboratories represent a promising alternative by providing a more effective learning experience and enhancing efficiency in experimental analysis (Tangka & Tani, 2022). It is hoped that the development of virtual laboratories can overcome learning barriers faced by students and reduce costs associated with experimental equipment in conventional laboratories. One example of a virtual laboratory is the PhET simulation lab.

One way to conduct virtual physics experiments is through the Physics Education Technology (PhET) application. PhET consists of a series of interactive simulations accessible online, developed by a team from the University of Colorado in the United States. This application is based on Java and Flash programming languages and has been proven beneficial in integrating computer technology into learning (Fithriani et al., 2016). PhET allows students to connect natural phenomena in everyday life with physics concepts, enhancing their interest in learning and understanding (Zahara et al., 2015), and is capable of establishing concrete cause-and-effect logic among various representations of related physical phenomena (Abdjul and Ntobuo, 2018). The application visualizes physics materials that are invisible to the naked eye and provides various measuring tools such as rulers, balances, stopwatches, and more, typically available in conventional laboratories (Amala et al., 2020). PhET also offers a range of physics experiments, which is useful if resources in the laboratory are limited. The main advantage of PhET is its ability to conduct ideal experiments, which may be challenging to perform manually with physical tools. PhET is chosen for its Java-based programming, particularly featuring the Easy Java Simulation (EJS), which is designed to simplify the analysis of physics concepts through computer simulations. By using PhET simulations, it is expected that students can more effectively understand abstract physics concepts and connect them with real-life phenomena (Aziza, 2020).

Physics education at MA Bahrul Ulum, particularly in the topic of waves, employs various approaches including lectures and discussions. However, despite efforts using diverse teaching methods, the learning outcomes for the eleventh grade remain unsatisfactory. Although teachers have tried to encourage student participation, there is still a tendency towards inactivity and a lack of synergy in the learning process. Traditional media such as blackboards for explaining formulas and textbooks remain the primary choices in physics education. Based on observational data and interviews with students and physics teachers at MA Bahrul Ulum, the average score of daily tests in physics, especially on the concept of heat, is still below the minimum mastery criteria (KKM). This fact is evidenced by the average daily test scores in the academic year 2021/2022 at 63.51, and in 2022/2023 at 65.70, where the school's set KKM is 75, with only 70% of students achieving it.

Initial observations also indicate that the condition of the Physics laboratory is still inadequate due to incomplete facilities and infrastructure, including insufficient laboratory equipment. The concept of heat requires demonstrative explanation through experiments using measuring instruments. The underuse of the laboratory for experiments results in low science process skills among students, which involve cognitive abilities, psychomotor skills, and social skills that, when taught, make science learning more meaningful. These science process skills include the abilities to think, reason, and act logically in researching and constructing scientific concepts that can be applied in problem-solving (Elvanisi et al., 2018).

Previous studies shows the utilizing of PhET application has been shown to have a positive impact on students' learning outcomes across various disciplines. Research studies have consistently demonstrated the effectiveness of PhET simulations in enhancing students' motivation, conceptual understanding, cognitive learning outcomes, and problem-solving skills (Banda & Nzabahimana, 2022; Inayah & Masruroh, 2021; Susilawati et al., 2022; Wartono et al., 2018). These studies have highlighted that PhET simulations not only improve students' academic achievement but also increase their motivation levels, making the learning process more engaging and effective. The PhET application can also serve as an alternative for conducting physics experiments. Students can perform experiments anywhere and anytime according to their needs. Specifically, the objective of this study is to determine the effectiveness of the PhET virtual labs application in enhancing students' science process skills in the topic of mechanical waves.

Novelty of the Current Study

This study introduces a novel approach by assessing the impact of the PhET virtual laboratory on students' science process skills specifically in the context of mechanical waves at MA Bahrul Ulum, an area that has not been deeply explored in existing literature. Previous research has predominantly focused on the general efficacy of PhET simulations across various scientific disciplines and topics, with an emphasis on cognitive and motivational outcomes. However, this research delves into the specific application of these virtual labs in enhancing practical science process skills, which include observation, experimentation, and data analysis, tailored to the mechanics of wave phenomena. This research endeavors to fill a critical gap by providing empirical data on how virtual laboratories can influence students' science process skills. While previous studies have shown that virtual labs improve understanding and engagement, this study extends these findings by examining how these tools can also foster a scientific mindsets, which are essential for collaborative and practical science work. By integrating virtual labs into the learning at MA Bahrul Ulum, the study aims to demonstrate a comprehensive model of educational technology's role in advancing science education, particularly in under-resourced settings, thereby offering valuable insights for similar contexts globally.

METHODS

This study utilizes a research methodology referred to as the one-group pretest-posttest design, as outlined by Fraenkel et al. (2012). This design is a straightforward yet powerful tool for assessing the impact of an intervention within a single group of subjects. In this approach, data are collected twice from the same subjects: once before the intervention is implemented (pretest) and once after (posttest). This method is particularly useful for measuring the changes in variables or behaviors directly attributable to the intervention, as it allows for direct comparison of conditions before and after the application of the experimental treatment. The research design is provided in Figure 1.

$$O_1 \quad X \quad O_2$$

Figure 1. The one group pretest-posttest design (Fraenkel et al., 2012)

The effectiveness of the intervention is determined by analyzing the differences between the pretest and posttest results. If the posttest scores show a significant improvement over the pretest scores, it can be inferred that the intervention had a positive effect. This design is ideal for educational and psychological research, where the same group of subjects can be observed under controlled conditions without the need for a control group. By focusing on the same group, researchers can directly attribute any changes observed in the outcome measures to the intervention, assuming no other influencing factors play a significant role during the study period. This setup helps in simplifying the experimental process while still yielding valuable insights into the effectiveness of the intervention studied.

This study was conducted at MA Bahrul Ulum Jombang, located in Tambakberas, Jombang. The location was selected to assess the science process skills following the use of a virtual laboratory employing PhET simulations for the topic of mechanical waves. The research period was the second semester of the 2022/2023 academic year. The population for this study comprised all eleventh-grade science students at MA Bahrul Ulum Jombang. The research sample consisted of students from class XI IPA 2 at MA Bahrul Ulum Jombang.

This study received written permission from MA Bahrul Ulum Jombang and adhered to strict ethical guidelines in involving students as research participants. Full consent was obtained from students , emphasizing the voluntary nature of their participation and the confidentiality of their responses. The ethical conduct of the research ensured no student was subjected to undue stress or discomfort, and all activities were seamlessly integrated into their usual educational routines, upholding the highest standards of ethical research practices.

The technique for data collection involved a test sheet for science process skills, which included pretest and posttest questions on the topic of mechanical waves. The assessed aspects of science process skills included formulating problems, hypothesizing, identifying variables, interpreting data, and drawing conclusions. Data were analyzed descriptively and statistically, where descriptive analysis used the parameters of average scores for the pretest, posttest, and N-Gain. The N-Gain equation is as follows (Meltzer, 2002 in Prihatiningtyas, 2020).

$$\text{N-Gain} = \frac{(\text{posttest score} - \text{pretest score})}{(\text{maximum score} - \text{pretest score})}$$

The N-Gain criteria (improvement in science process skills) can be seen in Table 1.

Table 1. Criteria of N-Gain

No.	Interval	Criteria
1	N-Gain ≥ 0,7	High
2	0,3 ≤ N-Gain < 0,7	Moderate
3	N-Gain < 0,3	Low

Table 1 presents the criteria for evaluating the N-Gain, which measures the improvement in science process skills. The table is structured into three categories based on the N-Gain values: a high improvement is indicated by an N-Gain of 0.7 or above, a moderate improvement is noted for N-Gain values between 0.3 and less than 0.7, and a low improvement is categorized for N-Gain values below 0.3. This classification helps in quantitatively assessing the extent of science process skills enhancement following educational interventions.

Subsequent to data collection, statistical analysis was utilized to evaluate students' science process skills, with a particular focus on testing the research hypotheses formulated for the study. The null hypothesis (H_0) posits that the use of the PhET virtual laboratory does not influence the assessment of science process skills in mechanical waves. Conversely, the alternative hypothesis (H_1) asserts that there is a significant impact of using the PhET virtual laboratory on assessing these skills. This stage of analysis is crucial to determine the effectiveness of the virtual lab in enhancing educational outcomes in physics.

The statistical methods used in this analysis included a paired t-test, which is employed to compare the mean scores before and after the intervention using the virtual lab. Prior to conducting the t-test, a normality test was performed on the data to ensure that the assumptions for parametric testing were satisfied. All statistical tests were carried out at a 0.05 significance level, using SPSS software, version 23.0. This approach allows for rigorous scrutiny of the data and helps validate the hypothesis by providing a clear statistical interpretation of the effect of the virtual laboratory on the learning process.

RESULTS AND DISCUSSION

The evaluation of students' science process skills was conducted both before and after the learning intervention using the PhET virtual laboratory on the topic of mechanical waves. This educational intervention involved students engaging with the PhET simulations as part of their learning activities. Throughout the learning process, students completed worksheets that were supported by the PhET simulations, and their performance on these activities was assessed based on predefined aspects of science process skills. The specific aspects evaluated included formulating problems, hypothesizing, identifying variables, interpreting data, and drawing conclusions. This structured approach ensured that the impact of the virtual laboratory on students' understanding and application of scientific concepts was systematically gauged.

Data collection for this study involved gathering scores from both pretest and posttest assessments related to the students' science process skills. These scores provided quantitative measures of the students' abilities in the specified aspects before and after the intervention. By comparing these scores, the study aimed to ascertain the effectiveness of the PhET virtual laboratory in enhancing students' scientific competencies. The collected data were systematically recorded and are presented in Table 2 of the study.

Table 2. Data results from pretest, posttest, and N-Gain from 30 students

No.	Name	Pretest score	Posttest score	N-Gain	Category
1	Respondent 1	43	96	0.93	High
2	Respondent 2	60	77	0.43	Moderate
3	Respondent 3	33	76	0.64	Moderate
4	Respondent 4	68	81	0.41	Moderate
5	Respondent 5	72	79	0.25	Low
6	Respondent 6	68	72	0.13	Low
7	Respondent 7	64	88	0.67	Moderate
8	Respondent 8	64	81	0.47	Moderate
9	Respondent 9	31	92	0.88	High
10	Respondent 10	68	87	0.59	Moderate
11	Respondent 11	55	80	0.56	Moderate
12	Respondent 12	47	68	0.40	Moderate
13	Respondent 13	22	84	0.79	High
14	Respondent 14	61	80	0.49	Moderate
15	Respondent 15	60	86	0.65	Moderate
16	Respondent 16	81	100	1.00	High
17	Respondent 17	86	100	1.00	High
18	Respondent 18	45	88	0.78	High
19	Respondent 19	69	84	0.48	Moderate
20	Respondent 20	29	88	0.83	High
21	Respondent 21	72	88	0.57	Moderate
22	Respondent 22	85	96	0.73	High
23	Respondent 23	43	88	0.79	High
24	Respondent 24	87	88	0.08	Low
25	Respondent 25	55	88	0.73	High
26	Respondent 26	47	96	0.92	High
27	Respondent 27	22	100	1.00	High

No.	Name	Pretest score	Posttest score	N-Gain	Category
28	Respondent 28	61	100	1.00	High
29	Responden 29	55	100	1.00	High
30	Responden 30	47	80	0.62	Moderate

Table 2 in the study presents a detailed overview of the results obtained from the pretest, posttest, and N-Gain calculations for 30 students who participated in the learning intervention involving the PhET virtual laboratory on mechanical waves. The data illustrate a range of outcomes for the students, where individual pretest and posttest scores highlight the degree of improvement after the intervention. For instance, Respondent 1 scored 43 on the pretest and improved dramatically to 96 on the posttest, resulting in a high N-Gain of 0.93, indicating significant learning gains. In contrast, some students like Respondent 24 showed minimal improvement (from 87 to 88), reflected by a low N-Gain of 0.08. The N-Gain values, categorized into high, moderate, and low, provide a quantitative measure of the effectiveness of the virtual lab in enhancing students' science process skills, with many students showing moderate to high improvements in their scores, emphasizing the PhET virtual laboratory's impact on enhancing students' understanding and application of scientific concepts.

Subsequently, before conducting parametric tests (hypothesis testing in statistics that is based on a normal distribution), a prerequisite assumption test, specifically a normality test, is performed. The normality test is used to determine whether the data distribution is normal or not. The results of the normality test are presented in Table 3.

Table 3. The result of normality test

Parameters		Pretest	Posttest
N		30	30
Normal	Mean	48.300	76.067
Parameters[a,b]	Std. Deviation	13,527	7.483
Most Extreme	Absolute	0.119	0.174
Differences	• Positive	0.056	0.117
	• Negative	-0.119	-0.174
Koimogorov-Smirnov Z		0.651	0.955
Asymp. Sig. (2-tailed)		0.790	0.322

The results presented in Table 3 indicate that the Asymptotic Significance (Asymp. Sig.) values for the pretest and posttest are 0.790 and 0.322, respectively. Both values are greater than 0.05, indicating that the data for both the pretest and posttest are normally distributed. Based on these results, the assumption of data normality is satisfied, allowing for the use of the paired t-test (dependent). The results of the statistical analysis are displayed in Table 4, Table 5, and Table 6.

Table 4. Descriptive statistics

Test parameters	Mean	N	Std. Deviation	Std. Error Mean
Pre-test	48.300	30	13.527	2.469
Post-test	76.067	30	7.483	1.366

Table 5. Paired samples correlation

Test parameters	N	Correlation	Sig.
Pair 1 Pretest and Posttest	30	254	0.176

Table 6. The Results of paired t-test

Pair	Mean	SD	SE	99% CID.		t	df	Sig.
				Lower	Upper			
Pretest-Postest	-27,767	13.698	2.501	-32.882	-22.652	-11.103	29	0.000

The calculation of the average scores for the pretest and posttest indicates that the average pretest score was 48, while the average posttest score was 76 (refer to Table 4), demonstrating an increase from the pretest to the posttest. This result is further confirmed by the statistical analysis (paired t-test), where the significance value is >0.05, meaning that H_1 is accepted (there is an effect of using the PhET virtual laboratory on assessing science process skills in mechanical waves). These findings are consistent with the research by Subeki et al. (2022), which states that the use of PhET simulations based on guided inquiry can enhance science process skills. Research by Saputra et al. (2017), Sari et al. (2013), and Prihatiningtyas et al. (2013) also affirms that the use of simulation media in learning not only enhances the effectiveness of learning compared to conventional methods but also facilitates students' understanding of the material, increases motivation, and engages students in the learning process. The PhET application is one effective example of enhancing students' cognitive learning outcomes through an interactive and enjoyable approach (Ningsih & Islami, 2023).

The findings of the current research are supported by the results of several previous studies, where the application of PhET simulations in physics learning has shown significant benefits in enhancing science process skills among students (Haryadi & Pujiastuti, 2020; Moore et al., 2014). These simulations provide dynamic access to multiple representations, make abstract concepts visible, scaffold inquiry, and allow for safe and quick experimentation, making learning engaging and fun for both students and teachers (Moore et al., 2014). The use of PhET simulations in teaching physics has become widespread, with a focus on improving students' understanding of complex topics like quantum mechanics and chemistry (McKagan et al., 2008; Wieman et al., 2010). Previous study has indicated that utilizing PhET simulations leads to improved learning outcomes and better understanding of science concepts compared to traditional methods (Verawati et al., 2022). The effectiveness of PhET simulation media in the physics learning process has been highlighted, emphasizing its role in enhancing students' science processing skills (Rizaldi et al., 2020; Danuarteu et al., 2023). Furthermore, the implementation of PhET simulations with various teaching models such as discovery learning has been found to significantly influence students' conceptual understanding of physics concepts (Prima et al., 2018; Anisa & Astriani, 2022). PhET simulations have also been effective in increasing students' interest in learning physics and improving their thinking skills (Saregar, 2016; Ismalia et al., 2022).

Moreover, PhET simulations have been recognized for their role in laboratory practices, with research showing that they can effectively serve as learning media to enhance students' concept understanding and motivation (Inayah & Masruroh, 2021). The use of PhET simulations in teaching specific topics like electrical circuits and light concepts has been found to be beneficial in improving students' understanding and learning abilities (Masruroh et al., 2020; Haryadi & Pujiastuti, 2019). Overall, the research supports the notion that integrating PhET simulations into physics education can lead to enhanced science process skills, better conceptual understanding, increased motivation, and improved learning outcomes among students (Yunzal & Casinillo, 2020; Rahmawati et al., 2022; Prasetya et al., 2022).

This study's findings also highlight the test results conducted by students before and after the learning intervention. Some students were already able to understand science process skills, achieving scores above the minimum mastery criteria (KKM) on the pretest. Details regarding the number of students who reached this understanding before using the PhET virtual laboratory on mechanical waves are presented in Table 7.

Table 7. Classification results of student pretest scores

No.	Score range	Frequency	Category
1.	90 - 100	0	Excellent
2.	75 - 89	0	Good
3.	60 - 74	10	Fair
4.	45 - 59	10	Poor
5.	0 - 44	10	Very Poor

The findings from Table 7 provide a clear insight into the initial understanding of science process skills among students before the intervention using the PhET virtual laboratory on mechanical waves. The classification of pretest scores reveals that none of the students were able to achieve the highest categories of understanding, labeled as "Excellent" or "Good," indicating a significant gap in their grasp of scientific processes. With 10 students falling into the "Fair" category, demonstrating some understanding but still below the desired level, and another 20 students categorized as "Poor" and "Very Poor," it's evident that a substantial portion of the class struggled significantly with these concepts. These initial results underscore the need for interventions that could potentially enhance the students' comprehension and application of science process skills, setting the stage for the utilization of the PhET virtual laboratory as a strategic tool to address these educational shortcomings. Furthermore, after implementing learning with the PhET virtual laboratory on mechanical waves, the results are recorded in Table 8.

Table 8. Classification results of student pretest scores

No.	Score range	Frequency	Category
1.	90 - 100	1	Excellent
2.	75 - 89	17	Good
3.	60 - 74	10	Fair
4.	45 - 59	2	Poor
5.	0 - 44	0	Very Poor

Following the implementation of the PhET virtual laboratory for mechanical waves, the post-intervention results recorded in Table 8 show a marked improvement in student performance. This shift is particularly notable at the higher end of the score spectrum, where previously no students had reached the "Excellent" or "Good" categories. Post-intervention, one student achieved an "Excellent" score, while a significant leap was seen in the "Good" category, with 17 students reaching this level. The number of students in the "Fair" category remained consistent at 10, but there was a dramatic reduction in the lower categories; only two students remained in the "Poor" category, and none were classified as "Very Poor." These results not only highlight the effectiveness of the PhET virtual laboratory in improving students' understanding of science process skills but also suggest that interactive and technology-enhanced learning tools can significantly alter the educational landscape, making scientific concepts more accessible and comprehensible to students. This improvement is crucial for fostering a deeper engagement and mastery of scientific principles among students.

Strong indications of the intervention's success are presented in Table 2, where the average N-Gain was calculated to be 0.51, categorizing it as moderate. Furthermore, the findings demonstrate a significant improvement in students' science process skills. The N-Gain is calculated based on the difference between the pretest and posttest results. In summary, the test results for science process skills are also displayed in Figure 2.

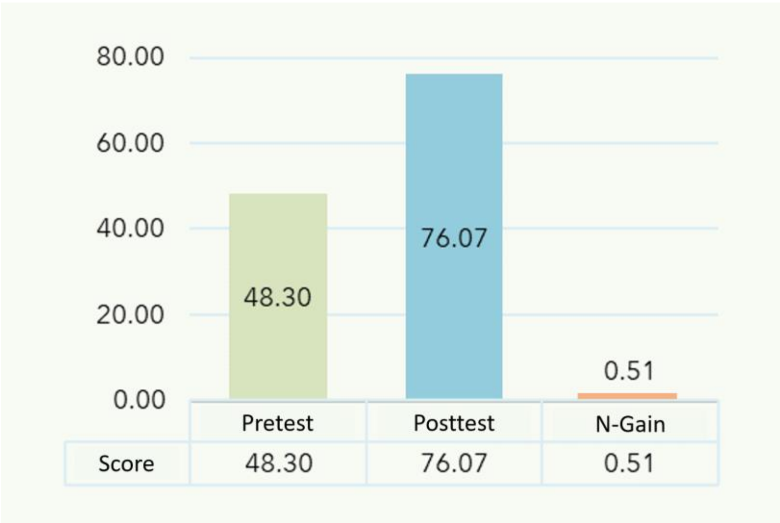

Figure 2. Graph of students' science process skills test results

Based on the data presented in Figure 2, the pretest and posttest analysis reveals a significant improvement in students' science process skills. Initially, the pretest results showed that students had an average score of 48.30, indicating that they had not fully grasped the unlearned science process skills concepts, making it challenging for them to respond adequately to the questions. However, after the learning intervention that incorporated the use of the PhET virtual laboratory in the context of mechanical waves, the posttest results displayed a notable increase, with the average student score reaching 76.07. This data suggests that the application of the PhET virtual laboratory in teaching mechanical waves has successfully enhanced students' abilities in science process skills positively.

Through practical experience in the PhET virtual laboratory, students developed essential science process skills such as observation, measurement, experimentation, and data analysis. They learned to plan and execute experiments, collect data, and evaluate the outcomes. This process not only enhanced their conceptual understanding of mechanical waves but also bolstered their skills in applying the scientific method. The hands-on approach facilitated by the virtual laboratory provides a dynamic learning environment that promotes active engagement and deeper comprehension of scientific concepts.

The results of the current study affirm that the use of the PhET virtual laboratory positively influences science process skills in the context of mechanical waves. This is evidenced by a significant increase in the N-Gain scores, which measure the improvement of students' skills from before to after the intervention. This finding aligns with the research of Arista et al. (2019), which demonstrated that students' physics learning outcomes using PhET-assisted virtual simulations are high, and the effectiveness in enhancing physics learning outcomes is considered substantial. Similarly, research by Saputra et al. (2020) showed that the use of the PhET application has a positive impact on student learning outcomes. Additionally, a study by Hikmah et al. (2017) found that the PhET application significantly affects students' conceptual understanding. Consequently, the use of the PhET virtual laboratory can be considered an effective instructional method for enhancing students' science process skills in understanding and applying concepts related to mechanical waves. This underscores the importance of integrating technology in education to enhance learning experiences and student achievements in the sciences. Establishing appropriate methods and employing practical media in the teaching and learning process can create an effective and enjoyable learning environment, facilitating students' ability to receive and process information.

Based on the findings of this study, it can be stated that the use of the PhET virtual laboratory on mechanical waves as a supportive educational medium can enhance students' science process skills. This highlights the potential of virtual labs to serve as powerful tools in scientific education, offering a blend of interactive and immersive learning that can significantly improve students' engagement and understanding of complex scientific concepts.

CONCLUSION

The research findings indicate that the use of a virtual laboratory in the study of mechanical waves significantly impacts students' science process skills. An average N-Gain score of 0.51 represents a moderate improvement, signifying tangible educational benefits from the intervention. Initially, students had a limited understanding of mechanical wave concepts, which posed challenges in grasping complex physical interactions. However, the implementation of the PhET virtual laboratory transformed their learning experience. By engaging with interactive simulations, students were able to directly observe and experiment with wave phenomena, enhancing their grasp of the concepts. This hands-on approach allowed them to develop key science process skills, such as observation, measurement, and data analysis. Post-intervention analysis revealed substantial and statistically significant enhancements in these skills, confirming that the virtual laboratory environment effectively supports and fosters deeper scientific understanding among students.

Statistical analysis of the study's results supports the acceptance of hypothesis (H_1), suggesting a positive influence of the PhET virtual laboratory on the assessment of science process skills related to mechanical waves. The integration of such technology into the science curriculum not only enriches the learning experience but also elevates students' academic achievements in scientific disciplines. The PhET virtual laboratory, by simulating real-world phenomena in an accessible and engaging format, provides a dynamic educational tool that bridges the gap between theoretical studies and practical understanding. Consequently, it can be concluded that the use of the PhET virtual laboratory in mechanical wave education is effective in enhancing students' science process skills. This conclusion underscores the value of incorporating advanced educational technologies in the classroom, which can lead to improved educational outcomes and better preparation of students for more complex scientific studies and careers.

RECOMMENDATION

Based on the findings of this study, several recommendations can be made to enhance the learning experience at MA Bahrul Ulum Jombang, particularly in the field of physics:

1. Integration of Technology: Utilizing technology such as the PhET virtual laboratory can be an effective strategy to enhance student learning experiences. Therefore, it is recommended to continue integrating technology into physics education, especially for topics requiring an understanding of complex concepts like mechanical waves. The integration of such digital tools can help demystify challenging concepts and offer interactive and engaging ways for students to explore scientific phenomena.
2. Teacher Training: It is crucial for teachers to receive adequate training in using educational technologies such as virtual laboratories. By understanding and mastering these tools, teachers can provide more engaging and effective learning experiences. Training should focus on both the technical use of the tools and pedagogical strategies to integrate them effectively into the curriculum, enhancing the overall teaching and learning process.
3. Curriculum Development: There is a need to review and possibly revise the physics curriculum to ensure that learning methods utilizing technologies like virtual laboratories are well integrated and support the achievement of learning objectives. This revision should aim to align the curriculum with new technological capabilities, ensuring that educational content and assessments leverage the benefits of these tools to enhance student understanding and performance.
4. Collaboration and Experience Sharing: Physics teachers at the school should engage in collaboration and share experiences related to the use of technology in teaching. This could include regular workshops or meetings where teachers discuss challenges, share best practices, and brainstorm new ideas for using technology effectively. Such collaboration can foster a community of practice that supports teacher development and enhances the learning environment.

Implementing these recommendations is expected to continually improve the quality of physics education at MA Bahrul Ulum Jombang and achieve better outcomes in student achievement in the sciences. By embracing these strategies, the school can ensure that its students are better prepared to understand and apply scientific concepts in their future educational and career endeavors.

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REFERENCES

Abdjul, T., & Ntobuo, N. E. (2018). *Buku Ajar Pembelajaran Fisika Berbasis Virtual-Lab*. Gorontalo: Universitas Negeri Gorontalo Press.

Akbar, M. R., Ningtyas, S., Aziz, F., Rini, F., Putra, I. N. A. S., Adhicandra, I., & Junaidi, S. (2023). *MULTIMEDIA: Teori dan Aplikasi dalam Dunia Pendidikan*. PT. Sonpedia Publishing Indonesia.

Amala, I. A., Indrawati, & Wicaksono, I. (2020). Efektivitas Aplikasi PhET Disertai LKS Materi Gerak dan Gaya untuk Pembelajaran IPA di SMP. *EduFisika: Jurnal Pendidikan Fisika, 5*(2), 85–91. https://doi.org/10.22437/edufisika.v5i02.9960

Anisa, V., & Astriani, D. (2022). Implementation of phet simulation with discovery learning model to improve understanding of dynamic electricity concepts. *Jurnal Pijar MIPA, 17*(3), 292-301. https://doi.org/10.29303/jpm.v17i3.3438

Ardius, A. (2019). Pemanfaatan Laboratorium Maya: Peluang dan Tantangan. *Jurnal Teknodik, 24*(2), 147-160. https://doi.org/10.32550/teknodik.v24i2.679

Arista, S., Darmawan, H., & Nurussaniah. (2019). Efektivitas Penggunaan Media Simulasi Virtual untuk Gerak Harmonis Sederhana di Singkawang. *Prosiding Seminar Nasional Pendidikan MIPA dan Teknologi, 1*(1), 88–96. https://journal.ikippgriptk.ac.id/index.php/snpmt2/article/view/1356

Astuti, I. A. D., & Handayani, S. (2018). Penggunaan *Virtual laboratory* berbasis PhET Simulation Untuk Menentukan Konstanta Wien. *Jurnal Penelitian Pembelajaran Fisika, 9*(2), 66-72. https://doi.org/10.26877/jp2f.v9i2.2487

Astuti, R. (2012). *Pembelajaran IPA dengan Pendekatan Ketrampilan Proses Sains menggunakan Metode Eksperimen Bebas Termodifikasi dan Eksperimen Terbimbing Ditinjau dari Sikap Ilmiah dan Motivasi Belajar Siswa (Pokok Bahasan Limbah dan Pemanfaatan Limbah Kelas XI Semes* (Doctoral dissertation, UNS (Sebelas Maret University)).

Aziza, A. N. (2020). *Pengaruh Media Simulasi Phet (Physics Education Technology) Terhadap Hasil Belajar Kimia Pada Materi Bentuk Molekul* (Bachelor's thesis, Jakarta: FITK UIN Syarif Hidayatullah Jakarta).

Banda, H., & Nzabahimana, J. (2022). The impact of physics education technology (phet) interactive simulation-based learning on motivation and academic achievement among malawian physics students. *Journal of Science Education and Technology, 32*(1), 127-141. https://doi.org/10.1007/s10956-022-10010-3

Danuarteu, M., Agustin, S., Carmelya, A., Fadhilah, I., Heong, Y., & Kaewpukdee, A. (2023). Can PhET simulate basic electronics circuits for undergraduate students? *Jurnal Infotel, 15*(1), 97-110. https://doi.org/10.20895/infotel.v15i1

Ekawati, Y., Sunarno, W., & Cari, C. (2017). Pembelajaran Fisika Melalui Discovery Learning Dengan Metode Eksperimen dan Demonstrasi Ditinjau dari Kemampuan Berpikir Kritis dan Kreativitas Siswa SMK Kelas X pada Materi Sifat Mekanik Bahan. *Inkuiri: Jurnal Pendidikan IPA, 6*(3), 17-28. https://doi.org/10.20961/inkuiri.v6i3.17832

Elvanisi, A., Hidayat, S., & Fadillah, E. N. (2018). Analisis keterampilan proses sains siswa sekolah menengah atas. *Jurnal Inovasi Pendidikan IPA, 4*(2), 245-252. http://dx.doi.org/10.21831/jipi.v4i2.21426

Fithriani, S. L., Halim, A., & Khaldun, I. (2016). Penggunaan media simulasi PhET dengan pendekatan inkuiri terbimbing untuk meningkatkan keterampilan berpikir kritis siswa pada pokok bahasan kalor di SMA Negeri 12 Banda Aceh. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education), 4*(2), 45-52.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to design and evaluate research* (8th ed.). New York: McGraw Hill.

Handayani, T. W. (2018). Peningkatan pemahaman konsep IPA menggunakan model pembelajaran inkuiri terbimbing di SD. *Edutainment, 6*(2), 130-153. https://doi.org/10.35438/e.v6i2.94

Haryadi, R., & Pujiastuti, H. (2020). Phet simulation software-based learning to improve science process skills. *Journal of Physics Conference Series, 1521*(2), 022017. https://doi.org/10.1088/1742-6596/1521/2/022017

Haryadi, R., & Pujiastuti, H. (2019). PhET simulation software-based learning to improve understanding ability in light concept. *Proceedings of the First International Conference on Technology and Educational Science, Bali, Indonesia*. https://doi.org/10.4108/eai.21-11-2018.2282121

Hasibuan, F. A., & Abidin, J. (2019). Upaya Peningkatan Pemahaman Konsep Fisika Mahasiswa Melalui Media Pembelajaran Berbasis PhET Simulation. *Jurnal Pendidikan Fisika, 8*(2), 102–108.

Hikmah, N., Saridewi, N., & Agung, S. (2017). Penerapan Laboratorium Virtual untuk Meningkatkan Pemahaman Konsep Siswa. *EduChemia (Jurnal Kimia dan Pendidikan), 2*(2), 186–195. https://doi.org/10.30870/EDUCHEMIA.V2I2.1608

Inayah, N. & Masruroh, M. (2021). PhET simulation effectiveness as laboratory practices learning media to improve students' concept understanding. *Prisma Sains, 9*(2), 152. https://doi.org/10.33394/j-ps.v9i2.2923

Ismalia, I., M, K., & Wahyuni, P. (2022). Investigating the use of phet simulation as a substitute for practical tools in understanding the concept of static electricity. *International Journal of Education and Teaching Zone, 1*(1), 20-25. https://doi.org/10.57092/ijetz.v1i1.7

Masruroh, N., Vivianti, A., Anggraeni, P., Waroh, S., & Wakhidah, N. (2020). Application of phet simulation to electrical circuits material in online learning. *Insecta Integrative Science Education and Teaching Activity Journal, 1*(2). https://doi.org/10.21154/insecta.v1i2.2312

McKagan, S., Perkins, K., Dubson, M., Malley, C., Reid, S., LeMaster, R., & Wieman, C. (2008). Developing and researching phet simulations for teaching quantum mechanics. *American Journal of Physics, 76*(4), 406-417. https://doi.org/10.1119/1.2885199

Moore, E., Chamberlain, J., Parson, R., & Perkins, K. (2014). PhET interactive simulations: transformative tools for teaching chemistry. *Journal of Chemical Education, 91*(8), 1191-1197. https://doi.org/10.1021/ed4005084

Ningsih, M. A., & Islami, N. (2023). Efektivitas Aplikasi PhET untuk Meningkatkan Hasil Belajar Kognitif pada Materi Gelombang Berjalan dan Gelombang Stasioner. *Jurnal Penelitian Pendidikan Fisika, 8*(4), 290-296.

Prasetya, I., Yusuf, M., & Buhungo, T. (2022). Description of students learning motivation towards the use of phet simulation in physics online learning in terms of self-efficacy and anxiety levels. *Jurnal Pijar MIPA, 17*(1), 23-27. https://doi.org/10.29303/jpm.v17i1.3218

Prihatiningtyas, S. (2018). Efektivitas Pembelajaran Fisika Berbasis Simulasi PhET dan Kitoptik Dengan Model Pembelajaranlangsung Untuk Menuntaskan Hasil Belajar Siswa. *EDUSCOPE: Jurnal Pendidikan, Pembelajaran, dan Teknologi, 3*(2), 16-22.

Prihatiningtyas, S., & Sholihah, F. N. (2020). Project based learning e-module to teach straight-motion material for prospective physics teachers. *Jurnal Pendidikan Fisika, 8*(3), 223-234. https://doi.org/10.26618/jpf.v8i3.3442

Prihatiningtyas, S., Prastowo, T., & Jatmiko, B. (2013). Implementasi simulasi PhET dan kit sederhana untuk mengajarkan keterampilan psikomotor siswa pada pokok bahasan alat optik. *Jurnal Pendidikan IPA Indonesia, 2*(1), 18–22. https://doi.org/10.15294/jpii.v2i1.2505

Prima, E., Putri, A., & Rustaman, N. (2018). Learning solar system using phet simulation to improve students' understanding and motivation. *Journal of Science Learning, 1*(2), 60. https://doi.org/10.17509/jsl.v1i2.10239

Rahmawati, Y., Zulhipri, Z., Hartanto, O., Falani, I., & Iriyadi, D. (2022). Students' conceptual understanding in chemistry learning using phet interactive simulations. *Journal of Technology and Science Education, 12*(2), 303. https://doi.org/10.3926/jotse.1597

Rizaldi, D., Jufri, A., & Jamal, J. (2020). Phet: simulasi interaktif dalam proses pembelajaran fisika. *Jurnal Ilmiah Profesi Pendidikan, 5*(1), 10-14. https://doi.org/10.29303/jipp.v5i1.103

Saputra, R., Susilawati, S., & Verawati, N. N. S. P. (2020). Pengaruh Penggunaan Media Simulasi Phet (Physics Education Technology) Terhadap Hasil Belajar Fisika. *Jurnal Pijar MIPA, 15*(2), 110–115. https://doi.org/10.29303/jpm.v15i2.1459

Saputra, T., Nur M., & Purnomo T. (2017). Desain Riset Perangkat Pembelajaran Menggunakan Media KIT Listrik yang Dilengkapi PhET Berbasis Inkuiri untuk Melatihkan Keterampilan Proses Sains Keterampilan Proses Sains. *USEJ: Unnes Science Education Journal, 5*(3), 1331–1342. https://doi.org/10.15294/usej.v5i3.13162

Saregar, A. (2016). Pembelajaran pengantar fisika kuantum dengan memanfaatkan media PhET simulation dan lkm melalui pendekatan saintifik: dampak pada minat dan penguasaan konsep mahasiswa. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni, 5*(1), 53-60. https://doi.org/10.24042/jpifalbiruni.v5i1.105

Sari, D., Lutfi, A., & Qosyim, A. (2013). Uji Coba Pembelajaran IPA dengan LKS sebagai Penunjang Media Virtual PhET pada Materi Hukum Archimedes. *Jurnal Pendidikan Sains E-Pensa, 1*(2), 15–20.

Subeki, R. S., Astriani, D., & Qosyim, A. (2022). Media simulasi PHET berbasis inkuiri terbimbing materi getaran dan gelombang terhadap peningkatan keterampilan proses sains peserta didik. *Pensa: e-Jurnal Pendidikan Sains, 10*(1), 75-80.

Susilawati, S., Doyan, A., Mulyadi, L., Abo, C., & Pineda, C. (2022). The effectiveness of modern physics learning tools using the phet virtual media assisted inquiry model in improving cognitive learning outcomes, science process skills, and scientific creativity of prospective teacher students. *Jurnal Penelitian Pendidikan IPA, 8*(1), 291-295. https://doi.org/10.29303/jppipa.v8i1.1304

Tangka, G., & Tani, D. (2022). Penerapan Media Pembelajaran Laboratorium Virtual Berbasis PhET pada Materi Larutan Asam Basa di SMA N 1 Likupang. *Jurnal Oxygenius, 4*(1), 17–22. https://doi.org/10.37033/ojce.v4i1.348

Verawati, N., Handriani, L., & Prahani, B. (2022). The experimental experience of motion kinematics in biology class using phet virtual simulation and its impact on learning outcomes. *International Journal of Essential Competencies in Education, 1*(1), 11-17. https://doi.org/10.36312/ijece.v1i1.729

Wartono, W., Suyudi, A., & Batlolona, J. (2018). Students' problem solving skills of physics on the gas kinetic theory material. *Journal of Education and Learning (Edulearn), 12*(2), 319-324. https://doi.org/10.11591/edulearn.v12i2.8424

Wibawanto, W. (2020). *Laboratorium virtual: konsep dan pengembangan simulasi fisika*. Semarang: LPPM Unnes.

Wieman, C., Adams, W., Loeblein, P., & Perkins, K. (2010). Teaching physics using phet simulations. *The Physics Teacher, 48*(4), 225-227. https://doi.org/10.1119/1.3361987

Yunzal, A., & Casinillo, L. (2020). Effect of physics education technology (phet) simulations: evidence from stem students' performance. *Journal of Education Research and Evaluation, 4*(3), 221. https://doi.org/10.23887/jere.v4i3.27450

Zahara, S. R., Yusrizal, Y., & Rahwanto, A. (2015). Pengaruh penggunaan media komputer berbasis simulasi physics education technology (PhET) terhadap hasil belajar dan keterampilan berfikir kritis siswa pada materi fluida statis. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education), 3*(1), 251-258.