

Application of Virtual Laboratory (PhET) Learning Media to Students' Scientific Literacy Skills at Junior High Schools

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Abstract: 21st-century learning demands that students possess critical thinking, creative, and problem-solving skills based on science literacy. However, observations at SMP Negeri 3 Kabila and SMP Negeri 1 Tapa indicate that science learning remains dominated by lecture methods and limited laboratory facilities, resulting in low process skills and student science literacy. This study aims to analyze the effect of implementing the PhET virtual laboratory learning media integrated with the Problem-Based Learning (PBL) model on students' science literacy skills regarding the topic of matter and its changes. This study uses a quantitative approach with a one-group pretest–posttest design, combined with a multi-site, replicated-treatment design. The research sample consisted of 112 seventh-grade students, selected via cluster sampling from two schools: SMP Negeri 3 Kabila and SMP Negeri 1 Tapa. The research instrument consisted of a science literacy test with 10 items that measured the ability to explain scientific phenomena, evaluate scientific investigations, and interpret scientific data. Data analysis used the Kolmogorov-Smirnov normality test, paired t-test (hypothesis test), and N-Gain calculation. The research results showed that the data were normally distributed and that the use of the PhET virtual laboratory media had a significant effect on students' science literacy skills, as indicated by t-values \geq t-table in all classes. The improvement in skills was also reinforced by the N-Gain value in the moderate category. This shows that PhET-based learning is effective in improving students' science literacy. So, it can be concluded that integrating the PhET virtual laboratory with the PBL model has a positive impact on students' science literacy skills in the topic of matter and its changes and can serve as an alternative learning medium in schools with limited laboratory facilities.

Keywords: Matter and Its Changes; PBL; PhET; Science Literacy; Virtual Laboratory.

Introduction

21st-century learning demands that students possess critical thinking, creativity, and problem-solving skills in technology-based scientific processes [1]. In science learning, students are not only required to understand concepts but also to use scientific knowledge to explain phenomena and make evidence-based decisions. The ability to utilize scientific knowledge, recognize problems, and draw conclusions based on evidence to understand natural phenomena and the impacts of changes caused by human activities is known as scientific literacy [2].

This component is important because it reflects students' ability to apply scientific ideas to scientific reasoning and investigation [3]. The classroom learning process is one of the factors that influences students' mastery of science literacy. Teacher-centered learning tends to make students passive and less engaged in the thinking process. Technology-based learning media has become one of the solutions to improve the quality of education. One relevant media is the PhET virtual laboratory, which provides interactive tools that allow students to conduct visual, safe, and flexible virtual experiments [4].

The PhET virtual laboratory media are an effective way to engage students actively and make learning enjoyable [5]. Additionally, the use of PhET also addresses technical barriers in schools with limited facilities, as the PhET virtual laboratory can be accessed for free on computers or

smartphones [6]. In previous research, it was shown that the use of the PhET virtual laboratory based on a differentiation approach significantly improved students' science literacy skills in identifying scientific problems, explaining phenomena, and drawing conclusions based on scientific evidence, with an N-Gain score categorized as high [7]. One important factor in creating a more personal and effective learning experience is the student's learning style. Learning style is the way a person processes, understands, and retains information. Given that each student has different learning preferences and needs, it is important to consider this [8].

Based on observations at SMP Negeri 3 Kabila and SMP Negeri 1 Tapa, both schools have implemented the independent curriculum. However, the quality of science education has not improved significantly because it is still dominated by the lecture method. Students tend to feel bored, less active, and have difficulty understanding material that requires practical activities or experiments. Additionally, experimental-based science learning faces challenges due to limited laboratory facilities. Not all equipment and practical materials are fully available. As a result, students cannot conduct experiments until they have a sufficient understanding of the teacher's explanation. This condition can lead to students lacking sufficient science process skills and can even reduce their science literacy. In science education, students must be given the opportunity to learn active observation, experimentation, and investigation. Curiosity increases, critical thinking skills improve, and

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scientific literacy rises. Therefore, learning innovations must be created to address laboratory limitations while simultaneously increasing student participation in science education.

The use of virtual laboratories has a positive impact on students' science literacy. The use of the PhET virtual laboratory in learning is effective and can improve students' science literacy skills [9]. Students can conduct experiments safely and flexibly, without relying on the availability of tools and materials in a real laboratory, by using virtual-laboratory-based learning media.

In this study, PhET is used as a virtual laboratory experiment medium integrated into the problem-based learning (PBL) model, guiding students to make improvements. Based on previous research, the use of PhET generally continues to focus on improving learning outcomes or science literacy. Research specifically examining science process literacy in the integration of PhET with the Problem-Based Learning (PBL) model at the junior high school level remains very limited. In addition, the implementation of PhET on the abstract material of matter and its changes has not been extensively explored. Therefore, this research contributes to more specifically analyzing the impact of integrating the PhET virtual laboratory with the PBL model on students' science literacy skills in the aspect of scientific processes at the junior high school level. This study aims to examine the effect of applying the interactive media of the

PhET virtual laboratory on students' science literacy skills in the topic of matter and its changes. This research is expected to serve as an alternative solution for science education in schools with limited laboratory facilities and also enhance students' ability to identify scientific problems.

This research aims to examine the impact of implementing the PhET virtual laboratory on students' science literacy skills regarding matter and its changes. This study is expected to serve as an alternative solution for science education in schools with limited laboratory facilities and also to enhance students' ability to identify scientific problems.

Research Methods

This study uses a quantitative approach with a quasi-experimental one-group pretest–posttest design, combined with a multi-site, replicated-treatment design. Quasi-experimental research is an experimental research that does not use random assignment. Rather utilizes existing groups to examine the effect of a treatment [10]. In the multi-site replicated treatment design approach, as outlined in the research [11], multi-site research is conducted across multiple locations with relatively similar characteristics and using the same data collection methods.

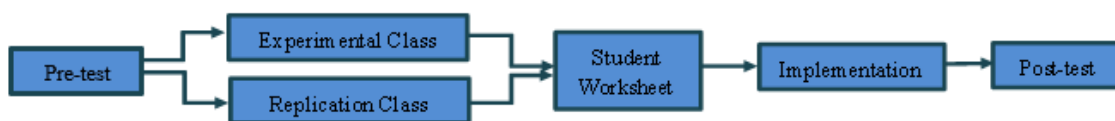


Figure 1. Research flowchart

The research flow diagram is shown in Figure 1. The research was conducted at SMP Negeri 3 Kabila and SMP Negeri 1 Tapa in the odd semester of the 2025/2026 academic year. The research population consists of all seventh-grade students, and a sample of 112 students was selected using cluster sampling, comprising one experimental class and three replication classes. The independent variable in this study is the interactive learning media based on the PhET Virtual Laboratory, while the dependent variable is the students' science literacy skills. The research instrument used was a science literacy test that included explaining scientific phenomena, evaluating scientific investigations, and interpreting scientific data, consisting of 10 questions administered in the pretest and posttest and tested for validity and reliability before use. The learning was conducted over three sessions using the Problem-Based Learning (PBL) model assisted by the PhET Virtual Laboratory. Data analysis techniques include normality tests (Kolmogorov-Smirnov), hypothesis tests (paired t-test), and are reinforced with N-Gain. The N-Gain categories are shown in Table 1 [12].

This research is also supported by implementation, student activities, and student questionnaires. In this study, the data were analyzed using several statistical techniques, namely the normality test, which is used to determine whether the pre-test and post-test data are normally distributed. The normality test is crucial as a prerequisite before conducting parametric statistical tests. Parametric

statistics are used to test population parameters or population sizes with sample data. This ensures that the data being tested is normally distributed [13]. Then, hypothesis testing was conducted to determine whether students' pre-test and post-test scores differed significantly after the treatment, and the n-gain test was used to assess improvement in students' conceptual understanding [14].

Table 1. N-Gain Value Categories

Gain Index	Criteria
$g > 0.70$	High
$0.30 < g < 0.70$	Medium
$0.00 < g < 0.30$	Low
$g = 0.00$	No improvement
Gain Index	Criteria

Results and Discussion

Students' science literacy skills were measured using a test instrument developed based on the science literacy indicators according to PISA 2022, namely: (1) explaining scientific phenomena clearly, (2) evaluating scientific investigations, and (3) interpreting data scientifically. The test was administered to students in four classes, namely the experimental class and replication 1 at SMP Negeri 3 Kabila, as well as replication 2 and replication 3 at SMP Negeri 1 Tapa. The percentage of students' science literacy achievement at each meeting is presented in Table 2. Based

on the OECD/PISA science literacy classification converted to percentages, students' achievement at the pretest stage was at levels 2-3 (low to moderate). After the learning process, the achievement increased to levels 4 to 5 (high to very high category). Overall, this data shows that the implementation of interactive learning media based on the PhET virtual laboratory is effective in improving and maintaining students' science literacy skills on all three PISA 2022 indicators across various classes and schools. Learning is

supported by educational resources and media based on virtual laboratory technology, such as the interactive PhET media, which are well-received and effectively used by students [15]. This allows students to actively engage in learning. The use of the PhET virtual laboratory media has a significant impact on students' science literacy, as evidenced by their active behavior, positive responses, and enthusiasm for learning [16].

Table 2. Percentage of Science Literacy Achievement

Class	Science Literacy Indicator					
	Explaining scientific phenomena clearly		Evaluating scientific research		Interpreting data scientifically	
	Pretest %	Post-test %	Pretest %	Post-test %	Pretest %	Post-test %
Experiment	37.3	66.8	50.3	81.6	76.5	93.3
Replication 1	53.9	74.4	38.5	75.5	65.2	96.5
Replication 2	39.7	85.9	37.9	77.8	63.9	75.0
Replication 3	38.1	60.3	40.8	78.8	42.9	92.5

The average pretest and posttest scores for each school were calculated in Excel, as shown in Table 3.

Table 3. Results of the Calculation of Average Pretest and Posttest Scores

No.	School	Class	Average	
			Pretest	Posttest
1.	SMP Negeri 3 Kabila	Experiment	52.82	79.25
		Replication 1	52.71	81.43
2.	SMP Negeri 1 Tapa	Replication 2	46.46	80.36
		Replication 3	40.39	75.54

Based on the data presented in Table 3, the pretest and posttest results show an increase in average scores across all classes at both SMP Negeri 3 Kabila and SMP Negeri 1 Tapa. This improvement indicates that learning using the interactive media of the PhET virtual laboratory has a positive impact on understanding the concepts of matter and its changes. This can be explained by the interactive PhET media, which allows students to connect theoretical concepts with visual representations of phenomena that resemble real conditions, making learning more meaningful.

Data from the experimental class, replication 1, replication 2, and replication 3 show that the interactive learning media of the PhET virtual laboratory effectively enhance students' understanding of science literacy. The average improvement in conceptual understanding fell into the moderate to high range (N-Gain 0.58–0.79). This success is due to the interactive media in the PhET virtual laboratory, which transform abstract learning into concrete learning and provide students with opportunities to learn interactively and independently.

Learning success can be measured by students' abilities, as shown in comparisons of pretest and post-test scores; a significant increase in post-test scores indicates that the learning media have achieved the learning objectives [17]. A substantial increase in scores after the learning treatment indicates that the media used has helped students better understand the material. Meanwhile, the analysis of student activities aims to measure and understand the various actions students perform during the learning process. The results of the observation of the implementation of learning

by the science teachers of the seventh grade at SMP Negeri 3 Kabila and SMP Negeri 1 Tapa are shown in Figures 2, 3, 4, and 5.

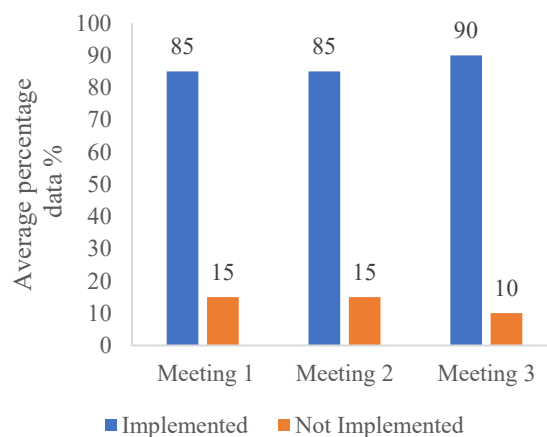


Figure 2. Percentage of Learning Implementation at SMP Negeri 3 Kabila (Experimental Class VII-A)

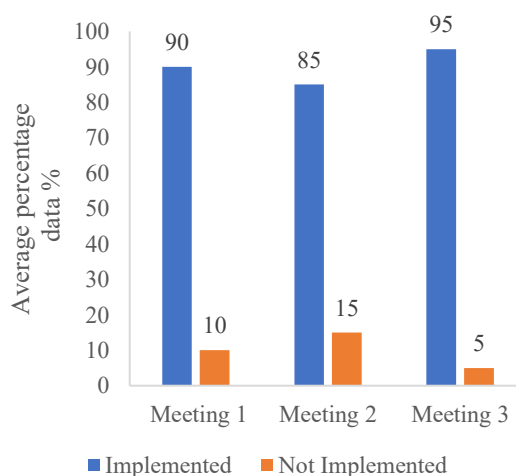


Figure 3. Percentage of Learning Implementation at SMP Negeri 3 Kabila (Replication Class 1 VII-B)

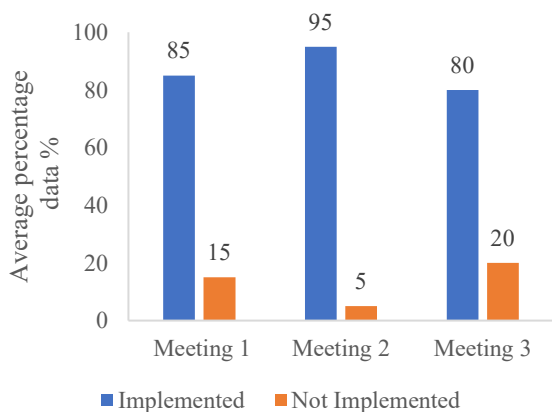


Figure 4. Analysis of Learning Implementation Results at SMP Negeri 1 Tapa (Replication Class 2 VII-C)

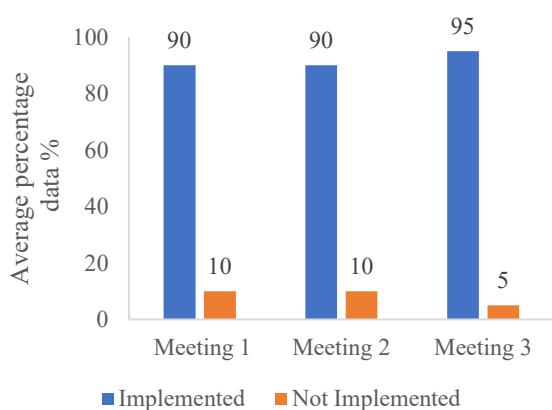


Figure 5. Analysis of Learning Implementation Results at SMP Negeri 1 Tapa (Replication Class 3 VII-D)

The level of observation results from the implementation of learning and student activities shows that the learning process is in the high category. The high student activity reflects that the PhET virtual laboratory-based learning encourages active student involvement in observing, experimenting, and drawing conclusions. Additionally, the questionnaire results indicate that students' responses to the use of the PhET virtual laboratory media are in the very good category. This indicates that learning using the PhET virtual laboratory is not only well implemented from the teacher's perspective but also encourages active student participation, thereby supporting optimal achievement of learning objectives. The level of student activity ranges from 85% to 90%, indicating that the class is very active.

The average achievement of the student questionnaire per indicator in the experimental class and replication 1 at SMP Negeri 3 Kabila falls into the very good category, and the replication 2 and replication 3 classes at SMP Negeri 1 Tapa also fall into the very good category. The percentage falls into the very good category. The very good category is determined by the assessment guidelines used in the questionnaire analysis, namely, criterion intervals based on the Likert scale. Converting the average score into a percentage and then matching it with a specific category allows for the categorization of Likert scale-based questionnaire assessments. Three tests (normality test,

hypothesis test, and n-gain analysis) were used to analyze the data obtained thereafter [18].

Data Normality Test

The results of the normality tests for the four classes are presented in Table 3, which specifically show the normality test results for the data from this study. The statistical test data obtained from the Kolmogorov-Smirnov analysis with the following steps: $F_i = |S(X_i) - F_0(X_i)|$ [19]. Summarized and presented in Table 4.

Table 4. Results of data normality testing

School	Class	F_i	K	Estado
SMP Negeri 3 Kabila	Experiment	0.872	0.25	Normally Distributed
SMP Negeri 1 Tapa	Replication 1	0.854	0.25	Normally Distributed
SMP Negeri 1 Tapa	Replication 2	0.870	0.25	Normally Distributed
SMP Negeri 1 Tapa	Replication 3	0.837	0.25	Normally Distributed

Based on Table 4, the normality test results indicate that the data are normally distributed, allowing the use of parametric statistical analysis. This indicates a significant effect of using interactive learning media from the PhET virtual laboratory on students' science literacy skills. These findings affirm that the improvement in science literacy did not occur by chance but rather resulted from the educational treatment provided. The results of the normality test indicate that the research data are normally distributed, meaning the distribution of student scores is symmetrical. This condition is an important requirement in the use of parametric statistical tests, such as the t-test. With the fulfillment of the normality assumption, the statistical analysis conducted can be declared valid and reliable. By using a normal distribution, parametric statistical techniques can be used to test hypotheses because the research variable data is evenly distributed above and below the mean [20].

Hypothesis Testing

After the prerequisite test is conducted and the data are found to be normally distributed, the next step is hypothesis testing. Hypothesis testing is a statistical procedure used to determine whether a statement or claim about a population parameter is true. Parametric hypothesis tests and paired sample t-tests are used to test the hypothesis [21]. The data from these hypothesis tests include the experimental class and replication 1 at SMP Negeri 3 Kabila, and replication 2 and replication 3 at SMP Negeri 1 Tapa. The results of these hypothesis tests are presented in Table 5 below.

Table 5. Hypothesis Testing Results

School	Class	t-count	t-table	Estado
SMP Negeri 3 Kabila	Exp.	8.984	2.056	H_a Accepted
SMP Negeri 1 Tapa	Rep. 1	11.145	2.056	H_a Accepted
SMP Negeri 1 Tapa	Rep. 2	6.173	2.056	H_a Accepted
SMP Negeri 1 Tapa	Rep. 3	11.334	2.056	H_a Accepted

Based on Table 5, the hypothesis test results show that $T_{hitung} \geq T_{tabel}$ in all classes, indicating a significant effect of using interactive learning media in the PhET virtual laboratory on students' science literacy skills. The impact of using interactive learning media based on the PhET virtual laboratory is evident in the science literacy results and the significant increase in students' Post-test scores after the pretest. This indicates a significant difference between the conditions before and after treatment. Thus, the use of the PhET virtual laboratory learning media has proven to have a significant impact on students' science literacy. Statistically, these findings confirm that the alternative hypothesis (H_a) is accepted, while the null hypothesis (H_0) is rejected. If the $T_{hitung} \geq T_{tabel}$ at a given level, then H_0 is rejected and H_a is accepted. This indicates that the treatment in the study, namely the use of PhET virtual-laboratory-based learning media, significantly affects the measured variable, students' science literacy [22].

N-Gain Test

The results of this N-gain analysis reflect how learning has improved students' understanding of the taught topic. The calculation of this improvement is based on the formula $N\text{-gain} = (\text{Post-test Score} - \text{Pre-test Score}) / (\text{Ideal Score} - \text{Pre-test Score})$ [23]. After the calculations were performed, the results obtained were then interpreted based on the criteria. Complete data on the N-gain test results are shown in Table 6.

Table 6. The N-Gain Test

School	Class	N-Gain	Criteria
SMP Negeri 3 Kabila	Experiment	0.59	Currently
SMP Negeri 1 Tapa	Replication 1	0.53	Currently
SMP Negeri 1 Tapa	Replication 2	0.61	Currently
SMP Negeri 3 Kabila	Replication 3	0.57	Currently

Based on Table 6, the extent of the increase in science literacy skills was analyzed using the N-gain test and fell into the moderate category across all classes. This moderate category indicates that PhET is quite effective in improving science literacy, although the increase has not yet reached the high category. The differences in N-gain values between classes are likely influenced by variations in students' initial abilities, differences in teachers' strategies in managing PhET-based virtual laboratory learning, and the level of student engagement during the learning process.

In general, all indicators of science literacy improved, indicating that learning through the PhET virtual laboratory is effective in helping students understand abstract science concepts. The PhET virtual laboratory can be used as an alternative to focus students' attention on teaching and learning activities. This trains students to conduct experiments in the real world [24]. Thus, students are no longer hindered from conducting experiments in learning by limitations in facilities and laboratory infrastructure, safety concerns, or a lack of funding for experiments. This is especially true for practical work conducted in the virtual world. In line with this, students' science literacy skills are greatly influenced by the PhET virtual laboratory, which can demonstrate real-world physical phenomena [25].

The advantage of using the PhET virtual laboratory is that students can access it from anywhere, anytime, without

the limitations of physical location. It also reduces the risk of accidents and exposure to hazardous materials, allowing users to conduct as many experiments as they want without limitations. One of the benefits of a virtual laboratory is that it can help explain abstract concepts that cannot be described with words. Additionally, a virtual laboratory can also serve as a place to conduct experiments that cannot be performed in a conventional laboratory [26]. Research on the application of interactive learning media based on the PhET virtual laboratory has demonstrated significant improvements in science literacy skills among SMPN students. By using interactive learning media based on the PhET virtual laboratory, the science literacy skills of SMPN students in science subjects, particularly in the topic of matter and its changes, have improved.

Conclusion

This research shows that integrating the PhET virtual laboratory into the PBL model affects students' science literacy skills in the topic of matter and its changes. This study shows that learning through the interactive media of the PhET virtual laboratory can enhance students' understanding of scientific concepts and their active engagement in scientific thinking. The practical implication of this research is that teachers can utilize PhET as an alternative learning medium to enhance the quality of science education, particularly for abstract material. For future research, it is recommended to use an experimental design with a control group and to expand the range of science literacy concepts studied to make the research results more comprehensive.

Author's Contribution

P.P. Abada: conceptualization, original draft writing, methodology; T. Abdjul: conceptualization, methodology, writing, reviewing, and editing; Nurhayati Nurhayati: Curation, original draft writing, writing, reviewing, and editing; A.H. Odja: Formal analysis, methodology, validation. M. Yusuf: Formal analysis, methodology, validation.

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