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STEM-Integrated PBL: Enhancing Science Literacy and Skills in Light Wave Material

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Abstract. This study looked for the influence and effectiveness of STEM-integrated PBL implementation on scientific literacy skills. The research method is quasi-experimental design, as described by Manova. The results obtained are: 1) there is an effect of implementing STEM-integrated PBL on scientific literacy skills in the domain of knowledge and skills with sig. = 0.000; 2) there is an effect of STEM-integrated PBL implementation on scientific literacy skills in the knowledge domain, with sig.= 0.000 content aspect, sig.= 0.000 procedural aspect, and sig.= 0.000 apistermic aspect; 3) there is an effect of implementing STEM-integrated PBL on scientific literacy skills in the skill domain, with sig.= 0.002 aspects of explaining natural phenomena, sig.= 0.001 aspects of designing, evaluating investigations, and sig.= 0.000 aspects of interpreting data, scientific evidence; 4) The implementation of STEM-integrated PBL is quite effective in increasing scientific literacy in the domain of knowledge and skills with an N-gain of 59% and 58%.

Keywords: PBL, STEM, science literacy

1. Introduction

Education today is situated in the 21st century, renowned for the era of the 4.0 revolution. 21st-century education aims to encourage students to adapt to the evolving times. One of the keys to facing the challenges of the 21st century is possessing scientific literacy skills [1]. The integration of scientific literacy with the science curriculum is considered to enhance scientific literacy skills, as seen in the curricula of Singapore, China, Hong Kong, and Canada [2–5].

According to PISA (Programme for International Student Assessment), scientific literacy is the ability to use scientific knowledge to identify questions and draw conclusions based on scientific evidence in order to understand and make decisions regarding nature and its changes due to human activity [6]. Scientific literacy is defined as the knowledge and scientific skills to identify questions, acquire new knowledge, explain scientific phenomena, and draw conclusions based on facts. It encompasses understanding the characteristics of science, being aware of how science and technology shape the natural, intellectual, and cultural environment, and having the willingness to engage with and care about science-related issues [7].

From the above description, we can conclude that scientific literacy is the ability to use scientific, critical, and creative thinking to understand encountered phenomena or solve problems, thus shaping students to be problem solvers. With problem-solving skills, students are expected to make decisions and draw conclusions based on facts, theories, and data, rather than mere assumptions and perceptions. Possessing scientific literacy skills can foster students' sensitivity and concern for their environment.

Evaluation and various efforts have been made by the government, one of which, in 2017, saw the Ministry of Education and Culture issuing a policy related to the national literacy movement. This movement has extended to the school level, with some schools incorporating literacy activities into their hidden curriculum [8]. However, this has not been able to significantly boost students' literacy achievement scores in Indonesia. This is evidenced by the decrease in PISA scores from 2018 compared to 2015. Scientific literacy scores dropped from 403 to 389 [6].

In 2019, the Ministry of Education and Culture launched the "Merdeka Belajar" (Freedom to Learn) policy. This major policy aims to transform the management of education in Indonesia. One of its key changes is the abolition of the National Exam (also called UN), which has been replaced by the National Assessment (also called AN). The National Assessment (AN) consists of three components: the Minimum Competency Assessment (also called AKM), the Character Survey, and the Environmental Survey [9].

The transition from the National Exam (UN) to the National Assessment (AN) signifies a shift to a new paradigm in the education evaluation system and an improvement in educational assessment in Indonesia. The changes in the assessment and evaluation system implemented by the government should also be accompanied by changes in teaching practices within the classroom. Conventional, teacher-centered teaching must be transformed into student-centered learning. One of the benefits of student-centered learning is that it encourages students to actively participate in classroom activities [10]. Teaching should be designed with instructional materials, learning media, and teaching models that place students at the center of the learning process. One such model that centers on students is problem-based learning [11]. Problem-based learning can enhance scientific literacy [12]. Interviews conducted with physics teachers of eleventh-grade students at MAN 2 Yogyakarta revealed that classroom instruction predominantly employs conventional methods, such as lectures and drill exercises. With a teacher-centered approach, the teaching activities do not focus on developing students' scientific literacy skills. The teachers have not yet developed instructional materials such as syllabi, lesson plans (RPP), Student Worksheets (LKPD), and assessment instruments based on scientific literacy. Additionally, there has been no scientific literacy-based assessment, resulting in students facing difficulties with scientific literacy-based questions. Despite adequate human resources and school facilities, time constraints have prevented the design of instruction that could enhance students' scientific literacy [13].

The interview results are consistent with a questionnaire administered to 73 students from the eleventh-grade science class at MAN 2 Yogyakarta for the 2021/2022 academic year. The questionnaire revealed that 79.5% of the students had difficulty solving scientific literacy-based questions.

The issues of low scientific literacy and the lack of instructional materials oriented towards developing scientific literacy skills led the researcher to propose an alternative solution: developing instructional materials using a Problem-Based Learning (PBL) model integrated with Science, Technology, Engineering, and Mathematics (STEM), assisted by PhET simulations. Problem-Based Learning (PBL) is a teaching model that centers on students, with PBL steps aligning with the development of scientific literacy skills, including explaining scientific phenomena, evaluating and designing scientific investigations, and interpreting data and evidence scientifically [14].

According to Alatas and Fauziah [15], PBL-based learning can enhance students' scientific literacy. In similar studies, it has been found that PBL-based learning improves students' scientific literacy across high, medium, and low ability groups [16]. According to the research findings of Pujiastutik [17] Pujiastutik's research indicates that the implementation of the PBL approach significantly enhances students' scientific literacy. When applying the PBL model to improve scientific literacy skills, it can be integrated with other learning approaches. According to Ismail, to boost scientific literacy, STEM-based learning can be incorporated into the PBL model [20]. STEM helps students apply their knowledge to design solutions as a problem-solving approach, making STEM-based learning a promising alternative for developing 21st-century skills, including scientific literacy. This is in line with research by Jasmi, which states that there is an impact of STEM-oriented PBL on students' critical thinking and scientific literacy skills [18].

STEM-based learning can also be delivered to students through engaging and socially-oriented activities. [19]. However, for abstract material, real-life practices may not always effectively build STEM skills. Therefore, virtual labs have been developed to enhance STEM skills. STEM-based virtual labs are effective in improving scientific literacy for both male and female students, particularly in the area of environmental pollution [20].

One of the virtual labs widely used to build scientific literacy skills is the Physics Education Technology (PhET) simulation. This interactive media provides students with the opportunity to study material at any time, repeat it as needed to understand concepts, guide themselves, and engage in independent learning. It helps students understand natural phenomena through scientific activities and mimics the methods scientists use to discover concepts, facts, laws, or principles of physics that are otherwise invisible [21]. According to research findings, [22], PhET Simulation is software that includes simulations capable of enhancing students' scientific literacy skills.

One of the simulations within PhET is an experiment related to light wave material, which is an abstract physics topic that is difficult for students to visualize. Abstract material is often prone to misconceptions [23]. Misconceptions are obstacles to understanding a phenomenon based on scientific conceptions due to beliefs that conflict but seem to be supported by reasonable arguments [21]. Misconceptions can also be interpreted as a conflict between students' initial conceptual understanding and correct concepts that have been proven correct by experts [24].

The research results of Wahyuningsih show that there are misconceptions in the concept of light wave material, especially in the material of light refraction (the direction of propagation of light in different media) [23]. Apart from that, also shows that students at Indragiri Hilir State Middle School experienced misconceptions about the material of light waves, which were highest in four concepts, namely the properties of light, reflection of light, the influence of the color of objects on the color of light, and the nature of light. polychromatic when passing colored objects [25]. Students also experience many misconceptions about the concept of light, namely assuming that the speed of propagation of light has nothing to do with the intermediate medium through which it passes [24].

Findings in the field show that there are still obstacles in students' understanding of science concepts. Science learning must be able to present phenomena in the learning process, however, science learning currently only involves memorizing material that students must master. This condition causes students' concept mastery to be low [26].

One of the phenomena that students can encounter in everyday life is light. Light phenomena that often appear in everyday life are related to the characteristics of light waves, including the concepts of reflection, refraction, decomposition, diffraction, interference and polarization. Light is considered an important study in everyday life. Without understanding the concept of light and its properties well, students cannot understand many scientific domains well [26].

Based on the description above, research will be carried out which aims to determine "The Effect of Implementing STEM-integrated PBL on the Science Literacy Ability of Students' Science Domain Knowledge and Skills on Light Waves Material".

2. Method

The independent variables in this research are the independent variable (X) STEM integrated PBL learning and learning using lecture and discussion methods. Meanwhile, the dependent variable is (Y) scientific literacy ability in the knowledge domain and skills domain.

This research is a Quasi-Experimental design with a Randomized Control Group Pre-test-Posttest Design research design. By involving a population of 58 MAN 2 Yogyakarta students. The experimental class consisting of 29 students was subjected to STEM integrated PBL learning and the control class of 29 students was subjected to learning using lecture and discussion methods.

Table 1. Research design.

Group	*Pre-test*	Treatment	*Post-test*
Experiment	O_1	STEM integrated PBL model	O_2
Control	O_1	Conventional Method (lecture and discussion)	O_2

Where O_1 as pre-test to measure the level of scientific literacy in the knowledge domain and science skills of students in both the experimental class and control class before receiving treatment, O_2 as post-test to measure the level of scientific literacy in the knowledge domain and science skills of students in both the experimental and control classes after receiving treatment.

This research instrument consists of (1) implementation instruments in the form of RPP and LKPD, and (2) data collection instruments consisting of science literacy ability tests in the knowledge domain and science skills domain. The data collection technique consists of giving a pre-test before treatment and a post-test after treatment. This test is to measure students' scientific literacy abilities in the knowledge domain in the content, procedural and epistermic aspects as well as scientific literacy skills in the skills domain in the aspects of explaining natural phenomena, aspects of designing and evaluating investigations and aspects of interpreting scientific data and evidence.

The scientific literacy ability test research instrument itself has gone through a feasibility test by three experts and has gone through the trial stage. From the feasibility test, it was found that the scientific literacy ability test instrument was very suitable for use with a feasibility score of 97%. Meanwhile, from the test results, it was found that 20 questions out of the 25 questions tested were declared valid and very reliable with a reliability value of 0.84.

To see the effect of implementing STEM integrated PBL with the help of PhET Simulation on scientific literacy abilities in the knowledge and science skills domain, the Manova test was used with the help of IBM SPSS Statistics 25 software. The decision making was that if sig < 0.005 then Ha was accepted. The Manova test itself was carried out after the Multivariate Normality Test and Homogeneity Test were fulfilled. Meanwhile, to determine the effectiveness of the implementation of integrated STEM PBL assisted by PhET Simulation on scientific literacy abilities in the domain of science knowledge and skills using the N-Gain test. The N-gain test formula was developed by Hake Sundayana [27].

$$Normalized\ gain(g) = \frac{Posttest\ score - pretest\ score}{Ideal\ score - Pretest\ score} \quad (1)$$

Meanwhile, the normalized gain category (g) according to Hake modified by the author is stated in table 2.

Table 2. Gain effectiveness interpretation categories.

Percentage (%)	Interpretation
< 40	Ineffective
40 – 55	Less effective
56 – 76	Effective enough
> 76	Effective

3. Results and discussion

Scientific literacy ability is the scientific ability to identify problems, discover new knowledge, draw conclusions based on scientific evidence through one's own discoveries based on trusted sources by utilizing technology and the surrounding environment so that ideas related to science emerge [28]. Students' scientific literacy abilities can be developed by implementing the STEM integrated PBL learning model with the help of PhET Simulation. This STEM-integrated PBL learning model can develop students' scientific literacy skills by training their abilities in solving problems related to phenomena that occur in the everyday environment. The results of the pre-test and post-test domain knowledge and science skills in the control class can be seen in table 3.

Table 3. Average results of domain control class science literacy knowledge and skills.

Domain	Indicator	*Pretest*	*Posttes*
Knowledge	Content	41	59
	Processure	46	62
	Epistemic	41	52
	Average domain knowledge	43	57
	Category	Very little	Less
Skills	Explain natural phenomena	47	63
	Design and evaluate scientific investigations	47	59
	Interpret data and evidence scientifically	38	53
	Skill domain average	44	58
	Category	Very little	Less

Based on the data in table 3, it can be seen that the average result of scientific literacy ability in the knowledge domain control class in the pre-test was 43 in the very poor category and in the science skills domain it was 44 in the very poor category. Meanwhile, in the post-test condition, the science literacy ability in the knowledge domain was 57 in the less category and the science skills domain was 58 in the less category.

The results of the pre-test and post-test of scientific literacy abilities in the domain of science knowledge and skills in the experimental class can be seen in table 4.

Table 4. Average scientific literacy results for the experimental class in the knowledge and skills domain.

Domain	Indicators	*Pretest*	*Posttest*
	Content	40	79
Knowledge	Processure	43	79
	Epistemic	40	70
	Average domain knowledge	41	76
	Category	Very little	Good
Skills	Explain natural phenomena	46	78
	Design and evaluate scientific investigations	46	76
	Interpret data and evidence scientifically	37	75
	Skill domain average	43	76
	Category	Very little	Good

Based on table 4, the average result of scientific literacy ability in the knowledge domain experimental class at the pre-test was 41 in the very poor category, while at the post-test it increased to 76 in the good category. In the science skills domain at the pretest it was 43 in the very poor category, while at the post-test it rose to 76 in the good category.

The average data on students' scientific literacy scores is then classified into levels of scientific literacy which according are divided into seven levels [29]. The calculation of the percentage of students' scientific literacy abilities in the knowledge and skills domain can be classified into scientific literacy levels, as shown in figure 1 and 2.

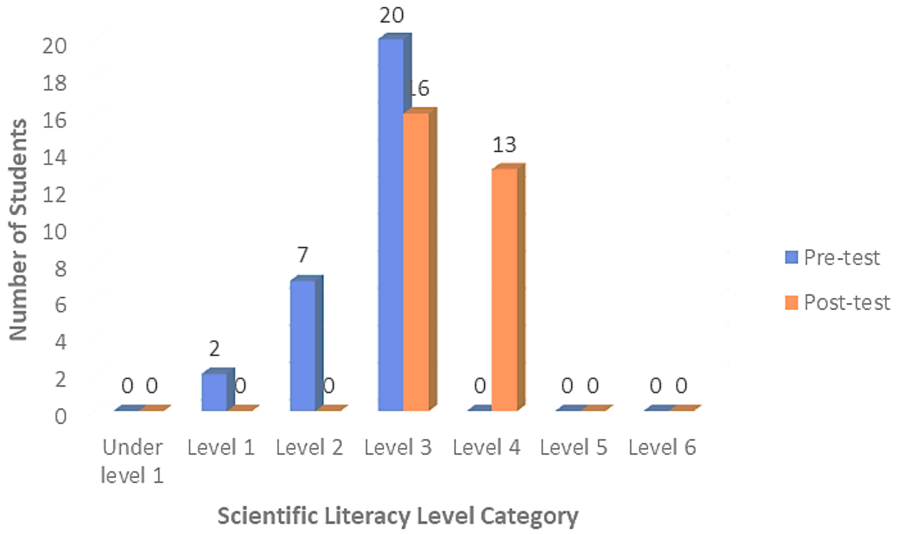

Figure 1. Science literacy level control class domain knowledge and skills.

Based on figures 1 and 2, the average scientific literacy level of control class students during the pre-test was at levels 1, 2 and 3, whereas after the learning activities it rose to levels 3 and 4. In the experimental class the students' scientific literacy level at the time The pre-test was at levels 2, 3, and 4, after being given learning treatment with the STEM integrated PBL model, the students' scientific literacy level based on the post-test results rose to levels 3, 4, 5, and 6.

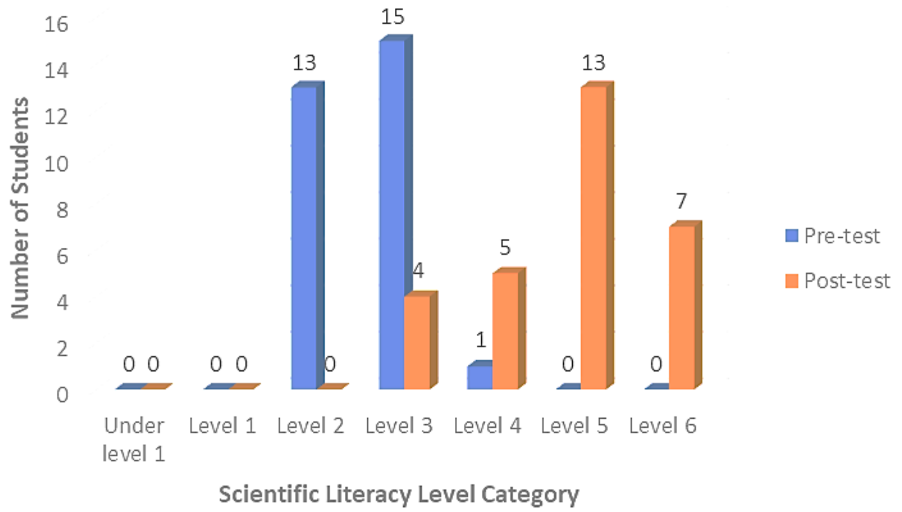

Figure 2. Experimental class science literacy level knowledge and skills domain.

In the control class, there were no students who could reach levels 5 and 6. The low achievement of students at levels 5 and 6 was because in previous learning the students had not had enough practice in working on questions linked from various sources of information and daily life situations. In accordance with expert opinion, the low achievement of scientific literacy at levels 5 and 6 is because students need to practice consistently in identifying, explaining, applying and analyzing scientific knowledge in various life situations [30].

Apart from the lack of practice, the low scientific literacy achievements of students at levels 5 and 6 are due to the fact that in the control class students were not given learning treatment with learning methods that were able to train scientific literacy skills. The learning methods used tend to be teacher-centred so they are less able to hone students' scientific literacy skills in both the knowledge domain and the science skills domain.

In contrast to the experimental class, after receiving STEM integrated PBL learning treatment there were 20 students out of 29 students or around 69% who were able to reach levels 5 and 6. This is in accordance with the results of research conducted by Adiwiguna which states that learning STEM-integrated PBL can effectively improve scientific literacy skills [31].

Students at level 1 have limited knowledge and can only provide explicit data explanations scientifically. Level 2 indicates that students possess scientific knowledge and can describe the results of their investigations. At level 3, students can articulate facts and knowledge to explain phenomena. Level 4 means students can reflect on actions and make decisions based on knowledge and scientific evidence. Level 5 signifies that students can provide explanations based on evidence and construct arguments through critical thinking. Finally, level 6 indicates that students demonstrate a high consistency in scientific thinking and can provide well-reasoned arguments for decision-making [32].

Students who reach level 5 are not only able to explain the definitions of the properties of light waves such as reflection, refraction, dispersion, interference, diffraction, and polarization, but they can also analyze a light phenomenon based on scientific evidence.

For example, in the case of the rainbow phenomenon, students can analyze that the rainbow involves not only the property of dispersion, as they might have read in their textbooks, but also includes reflection, refraction, and dispersion of light. Through investigation activities using PhET Simulation and simple artificial rainbow experiments, students can understand that the rainbow phenomenon involves these light wave properties [33].

Students who reach level 6 can evaluate arguments and evidence from various sources scientifically. For instance, when given experimental data related to Young’s experiment (question 24), students can determine the wavelength used. In addition to determining the wavelength, students can also conclude the type of light wave used by consulting other sources of information.

Based on the above analysis of literacy skills, it is observed that the experimental class, after receiving STEM-integrated PBL instruction, shows a better improvement in scientific literacy compared to the control class. However, to assess the effect of STEM-integrated PBL instruction on scientific literacy, a difference test is needed, such as MANOVA using IBM SPSS Statistics 25. To understand the impact of STEM-integrated PBL with PhET Simulation on scientific literacy in the knowledge and skills domains, the data must first be tested for normality and homogeneity. The multivariate normality test in this study uses a scatter plot of Mahalanobis distance and Chi-Square values, as shown in figure 3.

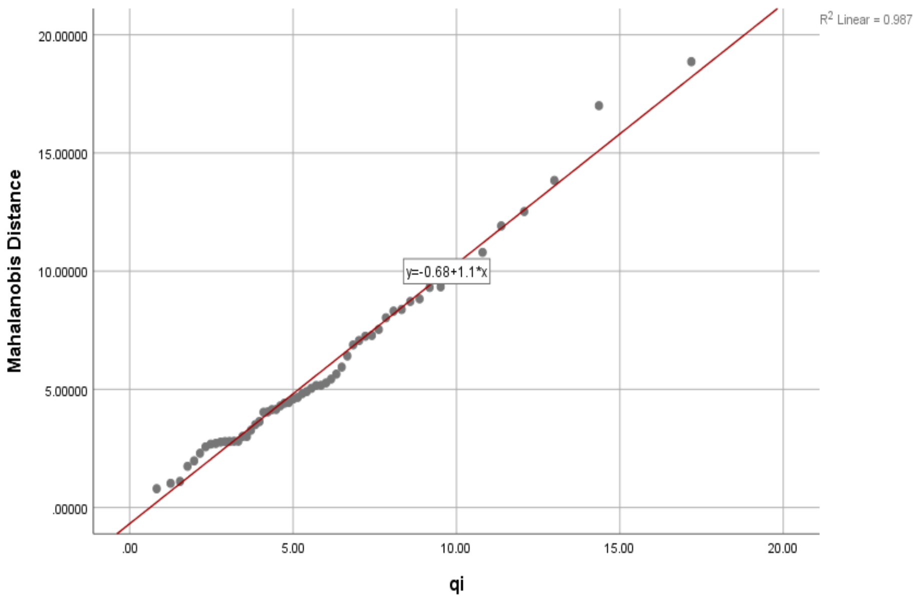

Figure 3. Scatter-plot of mahalanobis distance with chi-square.

Based on figure 3, the scatter plot appears to form a nearly straight line. This indicates that the data comes from a sample that is multivariately normally distributed.

Normality tests using scatter plots can sometimes be misleading; they may appear normal visually but be otherwise statistically. The normality test with scatter plots can be complemented by statistical tests, such as examining the correlation coefficient between Mahalanobis distance and Chi-Square. If the correlation value is higher than the critical value or the significance value is less than 0.05, it can be concluded that the data in the scatter plot comes from a multivariate normal sample. The results of the correlation test are shown in table 5.

Table 5. Correlation coefficient of mahalanobis distance with chi-square.

Pearson Correlation	Sig.
0,994	0,000

From table 5, the correlation coefficient obtained is 0.994, indicating a high correlation coefficient. The significance value obtained is also less than 0.05, specifically 0.000, which means there is a significant correlation. Therefore, it can be concluded that this scatter plot comes from a sample data that is normally distributed.

The homogeneity of the variance-covariance matrix was tested using Box's test of equality of covariate matrices. The results of this test can be seen in table 6.

Table 6. Homogeneity test of variance-covariance matrix with box's m.

Box's M	Sig.	Conditions	Decisions
51,488	0,001	> 0,005	Inhomogeneous

The results in Table 6 show that the homogeneity test for the variance-covariance matrix yielded a significance value of 0.001, which means sig. < 0.05, leading to the rejection of the null hypothesis (Ho). This indicates that the variance-covariance matrices between the control and experimental classes are not homogeneous.

Based on the prerequisite tests, it was found that the data comes from a normally distributed sample, while the variance-covariance matrix is stated to be non-homogeneous. Despite the non-homogeneity indicated by the variance-covariance matrix test, experts suggest that MANOVA can still be performed using Pillai's Trace for the calculations. This is because Pillai's Trace is robust to violations of the homogeneity assumption. The hypothesis test results using MANOVA with Pillai's Trace statistics can be seen in table 7.

Table 7. Multivariate test with pillai's trace.

Effect		F	Sig.	Conditions	Decisions
Class	Pillai's Trace	11,591	0.000	< 0,05	Significant

Table 7 illustrates the comparison of scientific literacy in the knowledge and skills domains between two classes: the experimental class and the control class. The MANOVA test using Pillai's Trace shows a significance value below 0.05, specifically 0.000, leading to the rejection of the null hypothesis (Ho). This indicates a significant difference in scientific literacy skills in both the knowledge and skills domains between the class that received STEM-integrated PBL with PhET simulation and the class that did not.

The presence or absence of differences in scientific literacy in the knowledge domain between the class receiving STEM-integrated PBL treatment and the class not receiving the treatment can be observed from the univariate test results, specifically the Test of Between-Subject Effects. The results of the univariate hypothesis tests can be seen in tables 8 and 9.

Table 8. Univariate analysis of scientific literacy in the knowledge domain.

Indicator	F	Sig.	Conditions	Decisions
Content	5760.069	0.000	< 0,05	Significant
Procedure	5800.000	0.000	< 0,05	Significant
Epistemic	5445.586	0.000	< 0,05	Significant

Table 8, the univariate analysis of scientific literacy in the knowledge domain shows that the significance values for the content, procedure, and epistemic indicators are each 0.000, which is smaller than 0.05, leading to the rejection of the null hypothesis (Ho). This indicates that there is a significant difference in scientific literacy in the knowledge domain between the experimental class, which received STEM-integrated PBL implementation, and the control class, which did not receive the PBL implementation.

Table 9. The univariate analysis of scientific literacy in the skills domain.

Indicator	F	Sig.	Conditions	Decisions
Explaining Natural Phenomena	4327.603	0.002	< 0,05	Significant
Designing and Evaluating Scientific Investigations	5215.517	0.001	< 0,05	Significant
Interpreting Data and Evidence Scientifically	7062.069	0.000	< 0,05	Significant

As seen in table 9, the science skills in the indicators of explaining phenomena, designing and evaluating scientific investigations, and interpreting data and evidence scientifically show significance values below 0.05 (namely 0.002, 0.001, and 0.000). Therefore, the null hypothesis (Ho) is rejected, and the alternative hypothesis (Ha) is accepted. It can be concluded that there is a significant difference in the scientific literacy skills domain between the experimental class, which received STEM-integrated PBL implementation, and the control class, which did not receive the PBL implementation.

The effectiveness of a teaching model is challenging to measure solely through the learning process due to the many factors that need to be observed. The most feasible approach is to measure the extent of target achievement from the pre-test (before treatment) to the post-test (after treatment). The percentage of N-gain is then calculated using the formula developed by Hake.

The results of the N-gain percentage calculations using Hake's formula for both the control and experimental classes can be seen in tables 10 and 11.

Table 10. Percentage of N-gain for the control class.

Domain	Indicator	Pre-test	Postest	N-Gain
Knowledge	Content	41	59	29%
	Procedure	46	62	29%
	Epistemic	41	52	18%
	Average Knowledge Domain	43	57	26%
Skills	Explaining Natural Phenomena	47	63	30%
	Designing and Evaluating Scientific Investigations	47	59	21%
	Interpreting Data and Evidence Scientifically	38	53	25%
	Average Science Skills Domain	44	58	26%

Tabel 11. Percentage of N-gain of experimental grade.

Domai	Indicators	Pre-test	Postest	N-Gain
Knowledge	Content	40	79	65%
	Procedure	43	79	63%
	Epistemic	41	70	50%
	Average Knowledge Indicator	41	76	59%
Skills	Explaining Natural Phenomena	46	77	60%
	Designing and Evaluating Scientific Investigations	46	76	56%
	Interpreting Data and Evidence Scientifically	37	73	60%
	Average Science Skills Indicator	43	75	58%

From the N-gain test results in Tables 10 and 11, it can be seen that the scientific literacy skills in the knowledge domain have an N-gain of 26% with a "less effective" category in the control class and 59% with a "sufficiently effective" category in the experimental class. For the skills domain, the N-gain is 26% with a "less effective" category in the control class and 58% with a "sufficiently effective" category in the experimental class.

This indicates that the implementation of the STEM-integrated PBL model with PhET simulation in the experimental class is quite effective in improving scientific literacy skills in both the knowledge and skills domains. As stated [27] a treatment model can be considered sufficiently effective if the N-gain percentage falls within the range of 56% to 76%.

4. Conclusion

Based on the above discussion, it can be concluded that scientific literacy skills, both in terms of knowledge and skills, are higher in the experimental class compared to the control class. The MANOVA test shows: 1) there is an effect of the implementation of STEM-integrated PBL on scientific literacy skills in the domains of knowledge and skills, with a significance level of 0.000; 2) there is an effect of the implementation of STEM-integrated PBL on scientific literacy in the knowledge domain, with significance levels of 0.000 for content aspects, 0.000 for procedural aspects, and 0.000 for epistemic aspects; 3) there is an effect of the implementation of STEM-integrated PBL on scientific literacy in the skills domain, with significance levels of 0.002 for explaining natural phenomena, 0.001 for designing and evaluating investigations, and 0.000 for interpreting data and evidence scientifically. The N-Gain test indicates that the implementation of STEM-integrated PBL is quite effective in improving scientific literacy skills in both the knowledge and skills domains, with N-gains of 59% and 58%, respectively.

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