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The Effectiveness of Problem-Based Learning Assisted by Interactive E-Worksheet Integrated with Socio-Scientific Issues on Students' Scientific Literacy Skill

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Abstract

Scientific literacy skill is a crucial competence that students must possess to face the challenges of a developing era. However, the level of scientific literacy among students in Indonesia, including at JHS 2 Ajibarang, is still relatively low. One effort to improve this skill is through the application of a Problem-Based Learning (PBL) model combined with E-Worksheet (Electronic Student Worksheet) integrated with Socio-Scientific Issues (SSI). This model presents real-life issues relevant to daily life to encourage students to think critically, solve problems, and understand scientific concepts more deeply. The integration of SSI into PBL supports the development of scientific literacy by engaging students in analyzing scientific concepts, practicing scientific reasoning, and applying scientific evidence to solve real-world problems and make informed decisions. This research aims to analyze the effectiveness of the PBL model assisted by interactive E-Worksheet integrated with SSI on improving students' scientific literacy skill and to evaluate the level of skill achievement in the experimental class. The research used a quantitative approach with a quasi-experimental design, specifically a pretest-posttest non-equivalent control group design. The sample consisted of class VIII A as the experimental class and VIII B as the control class. The results of the dependent t-test and independent t-test statistical analyses showed a significance value (2-tailed) of 0.000 < 0.05, indicating that the model is effective in improving students' scientific literacy. The average achievement of scientific literacy in the experimental class was also in the very high category. This model can be a strategic alternative to improve the scientific literacy of junior high school students.

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INTRODUCTION

The demands of a changing era require humans to continuously adapt in various aspects of life, including education. Scientific literacy skill are among the 16 essential skills needed in the Industrial Revolution era (WEF, 2015). Scientific literacy refers to the ability to identify scientific issues, understand scientific concepts, and use scientific evidence as a form of critical thinking in everyday life (OECD, 2023). Mastery of scientific literacy skill equips students to face the demands of the times and prepare for global competition (Nisrina et al., 2020; Safrizal, 2021). Scientific literacy also encourages students to propose appropriate solutions to challenges encountered in life (Putra et al., 2023), make informed decisions in various situations (Ke et al., 2021), and identify public issues based on scientific understanding (Hazen & Trefil, 2009). Therefore, improving students' scientific literacy has become an important goal in science education.

However, the level of students' scientific literacy in Indonesia remains relatively low. This condition was also found at JHS 2 Ajibarang, where students obtained an average score of 45 out of 100 based on a school-administered scientific literacy assessment. This result indicates that students still have difficulty answering scientific literacy-based questions. Several factors contribute to this problem, including students' low learning engagement and participation, as well as the limited use of innovative learning models in the classroom. In addition, the learning process is often insufficiently connected to real-life contexts, causing students to struggle in applying scientific concepts to everyday problems.

One effort to improve students' scientific literacy skill is through science learning that actively engages students in solving contextual problems (Queiruga-Dios et al., 2020). An appropriate learning model is therefore needed, and Problem-Based Learning (PBL) is considered a suitable approach to support scientific literacy skill. PBL presents real-world problems that encourage students to synthesize information, evaluate the validity of evidence, and develop deeper conceptual understanding (Alatas & Fauziah, 2020). Furthermore, the stages of PBL align with the dimensions of scientific literacy, including context, knowledge, and competence (Hafizah & Nurhaliza, 2021). Through these stages, students are encouraged to think critically and apply scientific reasoning in problem-solving activities.

Problem-Based Learning can be strengthened through the integration of Socio-Scientific Issues (SSI). SSI-based learning presents social issues closely related to science, enabling students to connect scientific knowledge with real-life situations (Hernández-Ramos et al., 2021). Previous studies have shown that SSI can improve students' scientific literacy, decision-making abilities, social engagement, and moral reasoning (Chowdhury et al., 2020). SSI also helps students explain events scientifically and evaluate issues from multiple perspectives (Ke et al., 2021). Therefore, the integration of SSI into PBL is expected to provide more meaningful learning experiences and support the development of scientific literacy skill.

In addition to learning models, the use of technology-based teaching materials can also support the learning process. Interactive E-Worksheet integrated with SSI has been reported to improve students' scientific literacy into a high category (Wumu et al., 2023). The use of E-Worksheet provides more varied and interactive learning activities that can increase students' engagement and motivation. Technology-assisted worksheets also help students understand complex concepts more easily and create a more enjoyable learning atmosphere (Amalia et al., 2023; Hernández-Ramos et al., 2021).

The novelty of this research lies in the integrated examination of the three domains of scientific literacy context, knowledge, and competence within a single comprehensive learning intervention, rather than investigating them partially or separately. Previous studies have generally focused only on one or two domains of scientific literacy, such as conceptual knowledge mastery or scientific reasoning skills, without analyzing the functional relationship among the domains.

In this study, the three domains were analyzed simultaneously and interconnectedly, providing a more comprehensive understanding of how students:

1. Understand socio-scientific issues in real-life contexts (context domain),
2. Master relevant scientific concepts and principles (knowledge domain), and

3. Use that knowledge to reason, evaluate evidence, and make science-based decisions (competence domain).

Although various studies have examined Problem-Based Learning, Socio-Scientific Issues, and the use of digital worksheets in science learning, there is still a research gap regarding how the integration of these three approaches simultaneously affects the three domains of scientific literacy (context, knowledge, and competence) within a single comprehensive and structured learning design. Therefore, the specific contribution of this study is to investigate the effectiveness of Problem-Based Learning assisted by interactive E-Worksheet integrated with Socio-Scientific Issues on all three domains of scientific literacy simultaneously, as well as to analyze the relationship between the stages of PBL and students' scientific literacy achievement indicators. JHS 2 Ajibarang was selected as the research site because the school has implemented the Merdeka Curriculum, has heterogeneous student characteristics, and still demonstrates scientific literacy outcomes that need improvement based on previous learning evaluations. Therefore, the school provides a relevant empirical context for testing the effectiveness of the learning innovation developed in this study.

METHOD

This study used a quantitative approach with a quasi-experimental research type and a nonequivalent control group design. To determine the students' initial abilities, a pre-treatment scientific literacy skill test was conducted. Afterward, the learning process was carried out. The experimental class was given the treatment of applying Problem-Based Learning (PBL) assisted by interactive E- Worksheet based on Socio-Scientific Issues (SSI), while the control class was given a direct instruction model. The research design is presented in Table 1.

Table 1. Nonequivalent Control Group Design

Group	***Pre-test***	**Treatment**	***Post-test***
Experiment	O_1	X	O_2
Control	O_3	Y	O_4

Explanation:
O_1 : Experimental class pre-test
O_2 : Experimental class post-test
X : Learning applies Problem-Based Learning assisted by E- Worksheet integrated with socio-scientific issues
Y : Learning applies direct instruction
O_3 : Control class pre-test
O_4 : Control class post-test

The students of class VIII at JHS 2 Ajibarang in the 2024/2025 academic year were the population in this study. Grade 8 consisted of 8 classes, namely classes 8A to 8H, with a total of 313 students. The technique used to determine the sample was cluster random sampling. Prior to this, a homogeneity test was conducted using the even-semester ASAS data for Science subjects. JHS 2 Ajibarang does not implement a gifted/advanced class system, so the students' abilities in each class are relatively similar. This is in line with the results of the homogeneity test, which stated that all classes were homogeneous. Based on these results, class VIII A was determined as the experimental class and class VIII B was determined as the control class.

The data collection technique used in this study was a test method, in the form of 24 multiple-choice questions for scientific literacy skill that were adapted to the scientific literacy skill indicators. Expert judgment validity testing was conducted on the instrument involving 2 lecturers and 3 teachers as validators with expertise in science education. The test instrument that had met the validity test, discriminating power, difficulty level, and reliability was used as the pretest and posttest. The test instrument that met the validity, discriminating power, difficulty level, and reliability criteria was used as the pretest and posttest instrument. The difficulty level of each item was categorized as moderate, the discriminating power ranged from sufficient to good categories, and the reliability was categorized as high. The data analysis technique used was inferential statistics, which involves making predictions and conclusions based on the tested data. The data were analyzed using SPSS version 22 with a significance level of $\alpha = 0.05$ as the basis for statistical decision-making. The prerequisite test conducted before the study was a homogeneity test. Subsequently, the final pretest

and posttest data were analyzed using a normality test, dependent t-test, independent t-test, percentage calculation, and n-gain test.

The structure of the interactive E-Worksheet in this study was designed in alignment with the stages of Problem-Based Learning. The E-Worksheet consisted of: (1) problem orientation through the presentation of contextual socio-scientific issues (such as global warming and environmental health), (2) problem formulation and initial hypothesis development, (3) collection and analysis of scientific information through data, images, and digital sources, (4) development of evidence-based solutions and arguments, and (5) reflection and evaluation of learning. Each stage was equipped with guiding questions, analytical activities, and interactive feedback explicitly intended to develop scientific literacy indicators in the domains of context, knowledge, and competence.

RESULTS AND DISCUSSION

The Effectiveness of Problem-Based Learning Assisted by Interactive E- Worksheet Integrated with Socio-Scientific Issues on Students' Scientific Literacy Skill

The purpose of this study was to analyze the effectiveness of Problem-Based Learning assisted by interactive E- Worksheet integrated with Socio-Scientific Issues on students' scientific literacy skill. To determine the research sample using the cluster random sampling technique, the data had to first pass a homogeneity test. Based on the results of the homogeneity test, a significance value of sig > 0.05 or 0.407 > 0.05 was obtained, meaning the data had a homogeneous variance. Thus, class VIII A was determined as the experimental class to apply Problem-Based Learning assisted by interactive E-Worksheet integrated with Socio-Scientific Issues, and class VIII B was the control class to apply direct instruction. After the research was conducted and the pretest and posttest data were obtained, the analysis was continued through a normality test. The Shapiro-Wilk normality test showed that all pretest and posttest data were normally distributed with a sig. value > 0.05. The next analysis was the dependent t-test, as presented in Table 2.

Table 2. Results of the Dependent T-Test for Experimental and Control Classes

Class	Data	Mean	Mean Difference	N	Sig.2-tailed
Experimental Class	Pretest	45.08	38.08	36	0.00
	Posttest	83.17		36	
Control Class	Pretest	44.25	16.14	36	0.00
	Posttest	60.39		36	

As shown in Table 3, the sig. (2-tailed) value is 0.00 < 0.05, which indicates a difference between the pretest and posttest scores in both classes. Although both the control and experimental classes showed an increase, the mean difference for the control class was lower than that of the experimental class. The experimental class, which used Problem-Based Learning assisted by interactive E- Worksheet integrated with Socio-Scientific Issues, outperformed the control class, which used direct instruction. After the different treatments, an independent t-test was conducted to find the difference in the posttest results between the two classes. The results of the independent t-test are presented in Table 3.

Table 3. Results of the Independent T-Test for the Posttest

F	Sig.	t	Sig. (2-tailed)	Mean Difference
0.473	0.494	14.361	0.000	22.778

The result of the independent t-test, with a sig. (2-tailed) value of 0.00<0.005, can be interpreted to mean there is a difference in students' scientific literacy skill between the two classes after they received different treatments. The higher the t-value, the greater the difference in students' scientific literacy skill. This difference is shown by a mean difference value of 22.778 points, where the experimental class was superior. To determine the

effectiveness category of the two classes, an n-gain test was conducted into 3 categories, low, medium, and high. The results of the n-gain test are presented in Table 4 below.

Tabel 4. Hasil Uji *N-Gain* Kelas Kontrol dan Eksperimen

Data	Mean		N-Gain	Kategori
	Pretest	Posttest		
Control	44	60.3	0.27	Low
Experiment	45	83.1	0.68	Mid

The table above shows that the n-gain score for the control class was 0.27, which is in the low category, while the n-gain score for the experimental class was 0.68, which is in the medium category. The difference in n-gain scores determines the effectiveness of the learning models used in the experimental and control classes. These results show that Problem-Based Learning assisted by interactive E- Worksheet integrated with Socio-Scientific Issues is more effective for students' scientific literacy skill when compared to the application of direct instruction in the control class.

The Achievement Level of Students' Scientific Literacy Skill Through Problem-Based Learning Assisted by Interactive E- Worksheet Integrated with Socio-Scientific Issues

The level of scientific literacy achievement was also analyzed using pretest and posttest data. The distribution of scientific literacy capabilities for students in the experimental class for each indicator, viewed from three aspects and nine indicators of scientific literacy, can be seen in Figure 1.

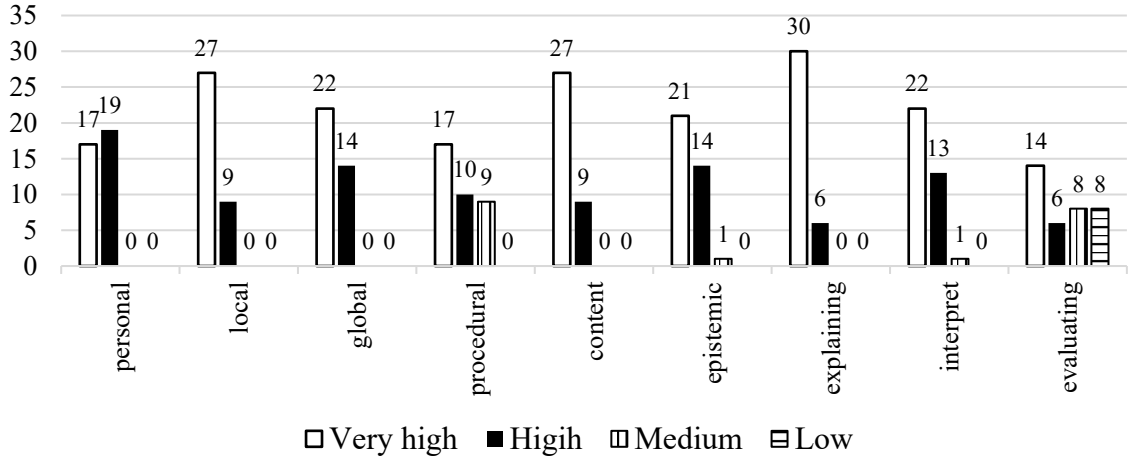

Figure 1. Post-Treatment Distribution of Students' Scientific Literacy Capabilities on Each Indicator in the Experimental Class

Figure 1 shows the distribution of students' scientific literacy capabilities across each indicator after the treatment. It is evident that the majority of students are in the high and very high categories for almost all scientific literacy indicators. The "explaining phenomena scientifically" indicator has the highest number of students in the very high category, with 30 students, which indicates an excellent level of mastery in that aspect. Meanwhile, the indicator with the lowest distribution is "evaluating and formulating scientific inquiry," showing a relatively balanced number of students across all four categories, with 8 students still in the low category. This suggests that while students' scientific literacy skill are generally high, there are still specific indicators that require further attention and reinforcement. The level of student achievement on each scientific literacy skill indicator is presented in Figure 2.

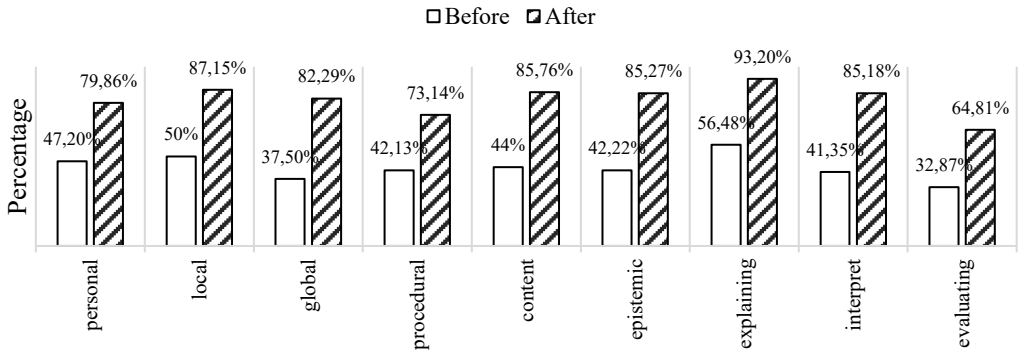

Figure 2. Comparison of Pre-Treatment and Post-Treatment Scientific Literacy Skill Achievement for the Experimental Class on Each Indicator

The graph above shows that the maximum increase is on the global indicator at 44.79%, while the minimum increase is on the "evaluating and designing scientific inquiry" indicator at 31.94%. However, overall, this graph illustrates that the treatment given in the learning process successfully improved students' overall scientific literacy achievement across all indicators. The difference lies only in the percentage of the increase.

The Effectiveness of Problem-Based Learning Assisted by Interactive E-Worksheet Integrated with Socio-Scientific Issues on Students' Scientific Literacy Skill

The research was conducted over seven meetings, with one meeting for the pretest, five for learning activities, and the final meeting for the posttest. The experimental class used Problem-Based Learning assisted by interactive E-WORKSHEET integrated with SSI, while the control class used a direct instruction model. Based on the pretest and posttest data analysis, it was found that the experimental class had superior scientific literacy skill compared to the control class, as evidenced by the differences in the dependent t-test and n-gain test results. This shows that Problem-Based Learning assisted by interactive E-WORKSHEET integrated with SSI is more effective than direct instruction.

Problem-based learning supports the achievement of students' scientific literacy skill through its learning steps. The steps in problem-based learning facilitate the achievement of students' scientific literacy skill through the correlation between each indicator and the problem-based learning activities (Hafizah & Nurhaliza, 2021). This intercorrelation can be seen in Table 5.

Table 5. Intercorrelation of Problem-Based Learning (PBL) and Scientific Literacy

Aspects of Literacy	Syntax	Correlation	Improvement
Context	1	Problem-Based Learning (PBL) presents real-world problems that are relevant to students' lives, allowing them to connect science with social and environmental issues.	38.20%
Knowledge	2	Problem-Based Learning (PBL) promotes independent exploration and group discussions to understand the material, thereby deepening science concepts through problem-solving.	38.60%
Competence	3-5	Students are trained to observe, formulate hypotheses, analyze information, and construct evidence-based arguments through discussions and the results of their investigations.	37.49%

The first step is orienting students to a problem. In this stage, students are encouraged to identify the problem presented in the E- Worksheet through videos or articles. The issues presented are Socio-Scientific Issues with personal, local, or global contexts and content, procedural, or epistemic knowledge. This stage encourages students to explore information related to the presented issues more deeply, triggering their curiosity. It sparks a spirit of learning and critical thinking as an initial step to improve students' scientific literacy skill (Adiwiguna et al., 2019). After considering the issues, students are guided to determine the specific problem. When a student is able to identify a problem, it indicates that they have been able to apply scientific concepts (Novitasari et al., 2022).

The second stage is organizing students for research, in which students are grouped into teams of 5–6 people. This grouping facilitates students in exchanging ideas, discussing, and broadening their perspectives. Through group discussions and collaborative problem-solving activities, students are encouraged to independently explore scientific concepts, which supports the development of the knowledge aspect of scientific literacy, as reflected in the 38.60% achievement shown in Table 5. Problem-Based Learning emphasizes the discussion process to find the best solution for the identified problems (Ariyanti & Yusro, 2023). Through this activity, students are actively encouraged to examine and explore more deeply the fundamental concepts of the material they are about to learn. This examination process begins from the first stage, which is when students identify the problem presented. With this activity, students do not just passively receive information but also build understanding through a critical thinking process regarding the context and material. This phase helps students acquire the required knowledge (Rakhmawati, 2021).

In the third stage, the teacher's role is to act as a facilitator, assisting students with independent and group investigations. Students are required to complete an interactive E- Worksheet that contains Socio-Scientific Issues and investigation procedures. This process helps develop students' procedural knowledge as they must design and select appropriate solution strategies. Furthermore, students are also challenged to evaluate the quality of the data they gather. They must understand the meaning of the collected information and critically analyze it based on learned concepts and theories. This is a crucial activity for developing students' scientific thinking skill, as it requires them to process information, draw conclusions, and form evidence-based arguments. Students are encouraged to consider the credibility of information from both its source and content. This activity is a practical application of epistemic knowledge, where students learn not to accept information blindly but to question and evaluate its basis and validity. The investigation process helps students improve their skill in analyzing and evaluating the credibility of information and data (Ariyanti & Yusro, 2023). This process not only involves applying systematic steps but also fosters students' ability to make decisions based on their understanding of relevant procedures. Through investigation activities, students can apply their knowledge directly and improve their thinking skill (Susilowati et al., 2022). This stage also contributed to the higher mean difference observed in the experimental class compared to the control class. The investigation and analysis activities encouraged students to actively construct knowledge and evaluate evidence, which strengthened their scientific literacy skills, particularly in the competence and knowledge aspects.

After students complete their investigation and interactive worksheet, the next step is to present their findings. In this stage, students also engage in discussions by responding to the investigation results of other groups. The activity of responding to other groups' results requires students to play an active role throughout the learning process (Janah & Dimas, 2021). This activity not only strengthens students' understanding of the material but also encourages them to develop scientific attitudes, such as curiosity, objectivity, and openness to various possibilities. Furthermore, this interpretation and analysis phase plays a significant role in achieving scientific literacy skill, particularly the ability to interpret data and results scientifically. In other words, this activity provides students with the opportunity to develop the skill to examine their investigation findings, connect them with scientific concepts, and present their discoveries in the form of logical and evidence-based arguments or

conclusions (Ensi, 2023; Hafizah & Nurhaliza, 2021).

The final step in the learning process is to analyze and evaluate. The teacher guides students to reflect on the results of their investigation and discussion and provides feedback. Students also receive active guidance from the teacher as a facilitator in evaluating the solution they created in the fourth phase. If it is found that the solution proposed previously is not entirely accurate, incomplete, or contains errors, students are directed to make improvements. This process includes revisiting the solution steps, re-examining the concepts used, and re-evaluating the solution to make it more accurate, logical, and appropriate for the given problem. This phase challenges students to think more deeply and creatively in creating, evaluating, and outlining the results of their investigation (Ensi, 2023; Rakhmawati, 2021). The activity of analyzing and evaluating helps develop students' scientific literacy skill in the competence of evaluating and designing scientific inquiry (Hafizah & Nurhaliza, 2021).

In addition to Problem-Based Learning, the use of E- Worksheet integrated with Socio-Scientific Issues (SSI) also helps support the achievement of students' scientific literacy skill. The integration of SSI encourages students to connect scientific concepts with real-life social issues, thereby enhancing their ability to analyze information, evaluate evidence, and make scientific decisions. Previous studies have shown that SSI-based learning can significantly improve students' scientific literacy and critical thinking skills compared to conventional learning methods (Chowdhury et al., 2020; Ke et al., 2021). In this study, the integration of SSI through interactive E-Worksheet supported students in understanding scientific concepts more contextually and contributed to the higher improvement in the experimental class. This approach offers several key advantages: it fosters students' curiosity and concern for real-world problems, expands their understanding of science concepts within everyday contexts, and encourages active participation in the investigation process—from questioning and collecting evidence to drawing conclusions. Furthermore, this method helps students develop the ability to present logical, data-based arguments, while the use of technology creates a more engaging learning atmosphere. These findings are consistent with the research of Wisdayana et al. (2025), who found that connecting science concepts with contextual issues can deepen students' understanding of the material. Similarly, the SSI approach itself has great potential to improve students' scientific literacy skill (Nurhalimah et al., 2024).

Students' Scientific Literacy Achievement Level Through Interactive E- Worksheet -Assisted Problem-Based Learning Integrated with Socio-Scientific Issues

The achievement level of students' scientific literacy skill was analyzed using descriptive statistical methods based on the posttest results. Based on the analysis, it was found that every indicator of scientific literacy skill showed an increase, as presented in Figure 2. This finding supports the conclusion that the students' overall achievement level is in the very high category.

The context aspect consists of three indicators, the first of which is personal context. This indicator includes situations and backgrounds related to an individual, family, or close social group. The ability of students in the experimental class on this indicator was in the very high and high categories, indicating that they were already able to apply scientific knowledge in a personal context to real-life situations. The significant improvement in scientific literacy skill in the experimental class compared to the control class is due to several factors. One of the main reasons is the use of interactive E- Worksheet, which effectively captured students' attention and aroused their curiosity. Students showed greater enthusiasm for learning with the E- Worksheet than with the printed version of the LKPD (Suryani & Rini, 2023). This interest encouraged students to be more active in exploring the issues presented in the initial, problem-orientation stage of the Problem-Based Learning model, especially those in a personal context that are most relevant to them. This curiosity about the unknown triggers their interest in learning, which in turn motivates them to continue exploring and deepening their understanding of the material (Noviyanto & Sumaryoto, 2021).

The second indicator is local context, which emphasizes situations, backgrounds, or issues

related to local or national communities. Student achievement on this indicator was in the very high and high categories. This success is closely tied to the process of identifying socio-scientific problems rooted in a local context, which helps students understand and interpret their knowledge. This is because students are more familiar with and understand the issues that occur in their surrounding environment. In line with the OECD's view (2019), the context used in learning must be relevant to students' lives. This relevance encourages active participation and makes it easier for them to understand new concepts and connect them with scientific principles. By using local phenomena, the learning process becomes more interesting and meaningful for students (Nugraha & Prabowo, 2022).

The global indicator showed the highest increase. This achievement is due to students' interest in global issues, which often emerges when they are introduced to topics they were not previously familiar with. In this situation, students tend to compare the state of their country with conditions in other countries. The presentation of real and relevant global issues encourages students to build diverse arguments and fosters an exploratory attitude. The activity of identifying problems through interactive worksheets integrated with Socio-Scientific Issues can foster curiosity and provide space for students to conduct a more in-depth analysis of the issues discussed. The SSI approach also helps students understand material concepts through the presentation of meaningful information (Yuniswara et al., 2024). The broader students' understanding of a topic, the more their scientific literacy skill develop (Noviyanto & Sumaryoto, 2021).

The next aspect is knowledge, which has three indicators. The first is content knowledge. One of the main factors in the effective mastery of content knowledge is the relevance of the material to daily life. The topics discussed, such as environmental health and global warming, have a direct connection to the reality students face. The examples used in the lessons are visualized through interactive worksheets based on Socio-Scientific Issues (SSI). This approach makes it easier for students to understand the subject matter while also developing their scientific literacy skill through personal experience and the freedom to explore concepts (Zairina & Hidayati, 2022). In addition, the use of digital devices supports students' comprehension of the material. During the learning process, students are given the freedom to search for information from various sources, whether through the internet or books, which expands their knowledge and allows them to discover new insights (Zairina & Hidayati, 2022).

The next indicator that showed an increase was procedural knowledge. Although it improved, the increase for this indicator was the minimum compared to the others. This low increase was caused by students' unfamiliarity with practical work. During experiments, they often did not understand the procedures, leading to practice that was disorganized and confusing. The lack of direct experience resulted in a suboptimal mastery of procedural knowledge, which is consistent with the findings of Sumarni et al. (2021) that practical work can influence the achievement of this indicator. Nevertheless, procedural knowledge still improved after the implementation of Problem-Based Learning assisted by interactive E- Worksheet based on Socio-Scientific Issues. This increase was influenced by three main factors: first, the application of PBL presented relevant problems that encouraged students to actively question and investigate (Widyaningrum & Wijayanti, 2019); second, the use of interactive worksheets guided the practical steps in a structured way and helped visualize the activities (Dewi & Firman, 2023); and third, the practical activity itself encouraged students to build conceptual understanding through direct experience, which aligns with the goals of scientific literacy (Noviyanto & Sumaryoto, 2021).

Epistemic knowledge also showed a significant increase of 43%. This improvement in the experimental class was influenced by the essay-type questions in the interactive worksheet, which encouraged students to provide in-depth answers. The questions in the investigation guide required students to prove the validity of the conclusions they had made (Sumarni et al., 2021). The investigation process itself also plays a crucial role in equipping students with an understanding of epistemic knowledge through its various stages. Activities such as observation, hypothesis formulation, and presenting evidence-based results all support the

achievement of this indicator (Randan et al., 2022). Furthermore, the mastery of epistemic knowledge is strengthened by a solid understanding of the material's content. This indicates that students not only understand scientific concepts theoretically but are also able to evaluate information critically and apply scientific reasoning in solving real-life problems. This is evident in the experimental class's ability to explain the concepts they learned, as they used their basic scientific knowledge to draw conclusions and ensure the validity of their investigation results (Limiansih et al., 2024).

Mastery of the "explaining phenomena scientifically" indicator depends on students' understanding of both content and context. These two aspects help students identify problems in various situations and construct scientific explanations based on facts and concepts (F. Rahmadani et al., 2022). E- Worksheet integrated with Socio-Scientific Issues (SSI) further supports this achievement by presenting phenomena relevant to daily life. This approach encourages students to understand the causes and scientific mechanisms of social phenomena, which simplifies science learning and improves scientific literacy (Purwandari et al., 2024). Discussion also plays a crucial role by giving students a space to ask questions, critique, and formulate more precise arguments (Rahmadani et al., 2023).

The competence of interpreting results and data scientifically showed an increase. Several factors contributed to this, including the third stage of Problem-Based Learning, which encourages students to seek information and conduct experiments to explain and solve problems. This activity helps them navigate the information, arguments, data, and results they obtain, which is in line with Ningrum et al. (2025), who state that problem-solving requires the ability to identify evidence and interpret investigation results. Additionally, problems integrated with Socio-Scientific Issues (SSI) train students to think critically because they cannot rely solely on rote memorization. This approach habituates students to investigating problems, evaluating the validity of information and arguments, and drawing conclusions (Sumarni et al., 2021).

The "evaluating and designing scientific inquiry" indicator showed the second-lowest increase. This was due to students' difficulty in answering questions that required them to propose solutions, as well as their limited experience in dealing with inquiry-based problems. Nevertheless, the majority of students were able to develop this skill. This improvement was supported by the implementation of Problem-Based Learning and interactive worksheets based on Socio-Scientific Issues (SSI). This learning model encourages students to solve problems through group discussions and promotes enthusiasm and perseverance in finding solutions throughout the learning process (Saputra, 2021). The interactive worksheet integrated with SSI also increased students' engagement and promoted scientific thinking, as reflected in their active questioning about real-life situations. In addition, the SSI approach enhanced students' motivation and strengthened their critical thinking skills in formulating solutions. By integrating science-based social issues, students became more capable of evaluating the accuracy and relevance of scientific data, thereby strengthening the evaluative aspect of scientific literacy (Zeidler et al., 2019). To further improve this aspect, teachers may incorporate more structured inquiry activities and metacognitive scaffolds, such as guiding questions, reflection prompts, and step-by-step investigation frameworks. These strategies can help students become more confident and systematic in designing investigations and evaluating scientific evidence.

The results of the study showed that although students' scientific literacy generally improved, several indicators demonstrated relatively lower improvement, particularly those related to procedural skills and inquiry design. This condition may have occurred because students were not yet accustomed to activities requiring independent investigation planning and open-ended reasoning, as previous learning practices were still dominated by conventional approaches focused on concept delivery and structured problem-solving. In addition, higher-order scientific literacy skills require a longer adaptation process compared to conceptual knowledge mastery.

From the implementation perspective, classroom conditions and learning contexts also influenced the achievement of learning outcomes. Limited instructional time, differences in students'

prior abilities, and the experiences of both teachers and students in using problem-based learning and digital media affected the optimization of each PBL stage. In several meetings, students still required intensive guidance in interpreting socio-scientific issues and connecting them with scientific concepts, indicating that the learning process had not yet fully developed into an independent and reflective process.

These findings have broader implications for science education, particularly in developing 21st-century scientific literacy. The results confirm that the integration of PBL, SSI, and interactive E-Worksheets has the potential to improve scientific literacy comprehensively. However, its implementation requires continuous pedagogical support, such as teacher training, adequate instructional time, and students' habituation to inquiry-based learning. Therefore, digital learning innovations should not only be conceptually designed but also contextually integrated to maximize their impact on the development of students' scientific literacy.

CONCLUSION

The implementation of the Problem-Based Learning model supported by interactive worksheets integrated with Socio-Scientific Issues (SSI) was proven to be effective at a moderate level in improving the scientific literacy skill of Class VIII students at JHS 2 Ajibarang on the topics of environmental health and global warming. This method was able to improve students' scientific literacy skill across all indicators, resulting in an overall average achievement of scientific literacy skill in the high category.

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