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Enhancing Students' Scientific Literacy through Socio-Scientific Issues-Based Project-Based Learning in Physics Education

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Abstract - *Students' scientific literacy in physics remains a major concern because classroom instruction often emphasizes conceptual understanding and mathematical problem-solving without sufficiently connecting physics concepts to real-life socio-scientific contexts. This study aimed to examine the effectiveness of Socio-Scientific Issues-based Project-Based Learning (SSI-PjBL) in improving eleventh-grade students' scientific literacy in physics education. A quantitative quasi-experimental method with a non-equivalent control group design was employed. The study involved 67 students from a private senior high school in Bandung, Indonesia, divided into an experimental group and a control group. The experimental group received SSI-PjBL instruction, while the control group received conventional instruction. Data were collected using a scientific literacy test developed based on three core competencies: explaining scientific phenomena, evaluating and designing scientific inquiry, and interpreting data and scientific evidence. The data were analyzed using descriptive statistics, normalized gain (N-Gain), an independent samples t-test, and Cohen's d effect size. The results showed that the experimental group achieved a greater improvement in scientific literacy than the control group. The experimental group obtained an N-Gain score of 0.61, categorized as moderate, whereas the control group obtained an N-Gain score of 0.33, categorized as low. The independent-samples t-test indicated a significant difference between the two groups ($p < 0.05$), with a large effect size (Cohen's $d = 0.92$). Improvement was observed across all scientific literacy indicators, with the highest gain in explaining scientific phenomena. The novelty of this study lies in integrating socio-scientific issues with project-based learning as a contextual instructional strategy for physics education. The findings conclude that SSI-PjBL effectively enhances students' scientific literacy by supporting the application of physics concepts to authentic problems. This study contributes to physics education by providing empirical evidence for a student-centered, contextual, and project-based approach aligned with 21st-century science learning goals.*

Keywords: *contextual learning; physics education; project-based learning; scientific literacy; socio-scientific issues.*

I. INTRODUCTION

Physics education in secondary schools plays an essential role in preparing students to understand natural phenomena, technological development, and science-related social problems (Hernandez et al., 2022; Halubova, 2024; Sokolowski, 2021). However, physics learning is still frequently dominated by conceptual explanation, mathematical derivation, and routine problem-solving. These practices are important for developing disciplinary knowledge, yet they are often insufficient when they are separated from meaningful real-life contexts. As a result, students may be able to solve formula-based problems but remain less capable of using physics concepts to explain everyday phenomena, evaluate scientific information, or make evidence-based decisions (Kujović et al., 2022). This condition indicates a gap between physics knowledge acquired in school and the broader competencies required in contemporary society. In the context of 21st-century education, this gap is critical because students are expected not only to master scientific concepts but also to apply them responsibly in personal, social, technological, and environmental contexts.

Scientific literacy has therefore become a central goal of science education. The Program for International Student Assessment defines scientific literacy as the capacity to use scientific knowledge to explain phenomena, evaluate and design scientific inquiry, and interpret data and evidence in real-world situations (OECD, 2023). This definition emphasizes that science learning should move beyond factual recall and procedural calculation toward the ability to reason with evidence and engage with science-related issues. Scientific literacy also includes the capacity to understand how science works, recognize the relationship between science and society, and participate in informed decision-making. Recent discussions in science education further emphasize that scientific literacy is increasingly connected to sustainability, technological innovation, environmental responsibility, and civic participation (Holbrook & Rannikmäe, 2009; Zeidler et al., 2023). Thus, improving students' scientific literacy is not merely an academic objective but also a social and educational necessity.

Despite its importance, students' scientific literacy in physics remains a persistent challenge (Azura, et al., 2021; Sartika et al., 2021). One major factor is that classroom instruction often presents physics as a set of abstract principles and equations rather than as a way of interpreting real-world phenomena. When learning is decontextualized, students tend to perceive physics as difficult, fragmented, and unrelated to their daily experiences. This situation limits knowledge transfer because students may understand concepts in a classroom setting but fail to apply them to unfamiliar problems. Previous studies have reported that students often struggle to connect physics concepts with contextual problems, suggesting that their understanding is frequently procedural or formula-based rather than conceptual and functional (Nurroniah et al., 2025; Aqilah et al., 2025). Therefore, physics instruction needs to provide learning experiences that help students relate concepts to authentic situations, analyze evidence, and construct scientifically grounded explanations.

Another issue is the limited opportunity for students to participate actively in the learning process. Teacher-centered instruction still dominates many classrooms, placing students as passive recipients of information rather than active constructors of knowledge. Such instruction may support short-term content coverage, but it leaves little room for inquiry, collaboration, argumentation, reflection, and problem-solving. These learning processes are essential for developing scientific literacy because students need opportunities to ask questions, evaluate evidence, compare alternative explanations, and communicate scientific ideas. Apriyani et al. (2021) argue that student-centered learning environments are important for strengthening scientific literacy in physics education because they encourage learners to engage more deeply with concepts and evidence. Accordingly, a more contextual, inquiry-oriented, and student-centered approach is required to address the limitations of conventional physics instruction.

Socio-Scientific Issues (SSI) offer a promising framework for strengthening the relevance of physics learning. SSI refers to complex, socially relevant issues that are closely related to science, technology, ethics, and public decision-making. In physics education, SSI may include topics such as renewable energy, electromagnetic radiation, climate-related technologies, transportation systems, electrical safety, and the social implications of technological innovation. These issues allow students to see physics as a discipline that contributes to understanding and solving real problems. SSI-based learning also encourages students to consider evidence, uncertainty, values, and social consequences when discussing scientific problems. Zeidler et al. (2023) explain that the SSI framework has contributed substantially to the development of functional scientific literacy by connecting scientific knowledge with reasoning, decision-making, and social responsibility. Similarly, Sadler (2004) emphasized that socio-scientific reasoning supports students' ability to evaluate evidence and construct arguments about controversial science-related issues. Therefore, integrating SSI into physics learning can make scientific concepts more meaningful and socially relevant.

However, SSI integration requires an instructional model that can systematically organize students' activities. Project-Based Learning (PjBL) provides such a structure by engaging students in extended inquiry, collaborative investigation, problem-solving, product development, and presentation. PjBL is grounded in constructivist learning principles, where students build understanding through active engagement with authentic tasks. Kokotsaki et al. (2016) describe project-based learning as a student-centered form of instruction characterized by autonomy, constructive investigation, collaboration, communication, and reflection within real-world practices. These characteristics align closely with the goals of scientific literacy, as students are required to use scientific knowledge to investigate problems, develop solutions, and communicate their reasoning. In physics learning, PjBL can help students move from passive reception of formulas toward active application of concepts in designing models, prototypes, or explanations. Recent studies also show that project-based learning can improve students' scientific abilities, creativity, and affective learning outcomes when implemented through meaningful physics projects (Fadilah et al., 2024; Praptama et al., 2023; Susilawati et al., 2025).

The integration of SSI and PjBL is particularly relevant because both approaches complement each other. SSI provides authentic and socially meaningful problems, while PjBL provides the pedagogical stages through which students can investigate, design, create, and reflect. In an SSI-PjBL environment, students are not only asked to learn physics concepts but also to apply them to analyze issues, propose solutions, and justify decisions with evidence. For example, when students investigate renewable energy, they may apply concepts of energy transformation, efficiency, electricity, and environmental impact while designing a project-based solution. This type of learning can support conceptual understanding, inquiry competence, data interpretation, collaboration, and communication. Several studies indicate that contextual and project-based learning can enhance scientific literacy by creating opportunities for students to connect scientific ideas to real-life problems and to engage in evidence-based reasoning (Rediani et al., 2024; Kokotsaki et al., 2016; Nurroniah et al., 2025).

Although SSI and PjBL have been widely discussed in science education, empirical studies that specifically examine their integration in physics learning remain limited, particularly regarding students' scientific literacy. Many studies have investigated PjBL as a general instructional model or SSI as a context for scientific argumentation. Still, fewer studies have focused on SSI-based Project-Based Learning as an integrated approach in secondary physics classrooms. This gap is important because physics has distinctive conceptual characteristics, including abstraction, mathematical representation, and close links with technological applications. Therefore, research is needed to examine whether SSI-PjBL can effectively support students in applying physics concepts to real-life contexts and improving their core scientific literacy competencies.

Based on these considerations, this study investigates the effectiveness of Socio-Scientific Issues-based Project-Based Learning in improving students' scientific literacy in physics education. Specifically, this study examines whether students who learn through SSI-PjBL show greater improvement in scientific literacy than those who experience conventional instruction. The study also considers students' development across scientific literacy indicators, including explaining scientific phenomena, evaluating and designing scientific inquiry, and interpreting data and scientific evidence (Lederman et al., 2013). By focusing on these competencies, this research is expected to contribute to the development of physics instruction that is more contextual, active, and aligned with international expectations for science education. The findings may also provide practical insights for teachers seeking to design learning experiences that connect physics concepts to real-world issues and support students in becoming scientifically literate citizens.

II. METHODS

This study employed a quantitative quasi-experimental design with a non-equivalent control group to examine the effectiveness of SSI-PjBL in improving students' scientific literacy in physics education. This design was selected because random assignment was not feasible in the natural classroom setting. Nevertheless, the design allowed the researcher to compare learning outcomes between an experimental group and a control group while maintaining appropriate control over the research procedures (Fraenkel et al., 2023).

The study was conducted in a private senior high school in Bandung, Indonesia. The participants were 67 eleventh-grade students enrolled in a physics course. They were divided into an experimental group (N = 33) and a control group (N = 34). The participants were selected using purposive sampling based on similarities in their prior academic abilities. This sampling technique was considered appropriate because the study was conducted in intact classroom groups and aimed to compare two groups with relatively comparable initial academic characteristics (Creswell & Creswell, 2018).

The physics topic selected for this study was closely related to real-life contexts, such as energy or electromagnetism, to ensure alignment with socio-scientific issues. The experimental group received SSI-PjBL instruction, while the control group was taught using conventional teaching methods. The SSI-PjBL instruction was designed to engage students in identifying real-world issues, conducting investigations, designing solutions based on physics concepts, developing products or prototypes, and presenting their project outcomes. In contrast, the conventional instruction in the control group was primarily teacher-centered, focusing on explanation, discussion, and problem-solving exercises.

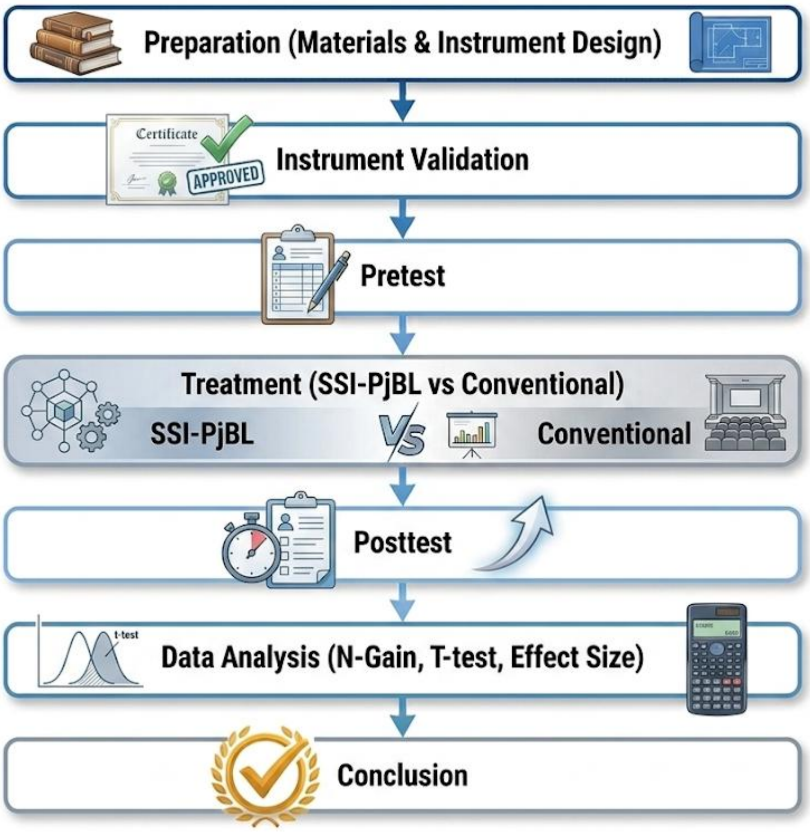

Figure 1. Research procedure flowchart

The research procedure consisted of three main stages: preparation, implementation, and data analysis. During the preparation stage, the researcher developed learning materials and research instruments, including lesson plans, student worksheets, SSI-based project scenarios, and the scientific literacy test. These materials were designed to support the implementation of SSI-PjBL and to align the learning activities with the scientific literacy competencies assessed in this study. The instruments and learning materials were then validated before implementation.

During the implementation stage, both groups were given a pretest to measure their initial level of scientific literacy. After the pretest, the experimental group participated in SSI-PjBL activities, whereas the control group received conventional instruction. At the end of the instructional treatment, both groups were given a posttest to measure their scientific literacy. The pretest and posttest scores were then compared to determine the improvement in students' scientific literacy and the effectiveness of the instructional treatment.

Table 1. Research design

Group	Pretest	Treatment	Posttest
Experimental	O_1	SSI-PjBL	O_2
Control	O_3	Conventional	O_4

This design enabled comparison of students' improvement in scientific literacy between the experimental and control groups. The use of pretest and posttest scores also allowed the researcher to examine changes in students' scientific literacy before and after the intervention. The main instrument used in this study was a scientific literacy test developed based on the OECD framework. The test measured three core competencies: explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically (OECD, 2023). The test consisted of open-ended, context-based questions related to socio-scientific issues. These questions were designed to assess students' ability to apply physics concepts in real-world situations, evaluate scientific problems, and interpret scientific information.

Table 2. Scientific literacy indicators

No	Indicator	Description
1	Explaining scientific phenomena	Applying physics concepts to explain real-world phenomena
2	Evaluating and designing scientific inquiry	Assessing and proposing scientific investigations
3	Interpreting data and scientific evidence	Analyzing data, graphs, and scientific information

Before the instrument was used in the study, it was validated through expert judgment and empirical testing. Expert judgment was used to assess the relevance of the test items to the scientific literacy indicators, the suitability of the socio-scientific contexts, and the clarity of the item wording. Empirical testing was then used to examine the quality of the items. Construct validity was analyzed using item-total correlation or Confirmatory Factor Analysis (CFA), while reliability was measured using Cronbach's Alpha to ensure internal consistency (Hair et al., 2024). These validation procedures were conducted to ensure that the instrument accurately measured students' scientific literacy.

Table 3. SSI-PjBL learning stages

Stage	Student activities
Issue orientation (SSI)	Identifying and understanding real-world issues
Investigation	Collecting and analyzing relevant information
Project design	Designing solutions based on physics concepts
Product development	Creating models or prototypes
Presentation & reflection	Presenting results and reflecting on the learning process

The SSI-PjBL learning stages were implemented to provide students with structured opportunities to connect physics concepts with socio-scientific contexts. In the issue orientation stage, students identified and discussed real-world issues related to the selected physics topic. During the investigation stage, students collected and analyzed relevant information to better understand the issue. In the project design stage, students proposed solutions using appropriate physics concepts. In the product development stage, students created models, prototypes, or other project outputs. Finally, in the presentation and reflection stage, students communicated their findings and reflected on the learning process.

The collected data were analyzed quantitatively using several statistical techniques. First, the N-Gain score was calculated to determine the level of improvement in students' scientific literacy from pretest to posttest. Second, prerequisite tests, including normality and homogeneity tests, were conducted to determine whether the data met the assumptions for parametric statistical analysis. If the data were normally distributed and homogeneous, an independent samples t-test was used to examine the difference between the experimental and control groups. ANCOVA could also be applied by treating pretest scores as covariates to control for initial differences between groups (Field, 2023). If the assumptions for parametric analysis were not met, the Mann–Whitney U test was used as a non-parametric alternative.

In addition to significance testing, effect size was calculated using Cohen's d to determine the magnitude of the treatment effect. Reporting effect size is important because it provides information about the practical significance of the intervention beyond statistical significance (Lakens, 2013). The analysis was also conducted for each scientific literacy indicator to identify which aspects of scientific literacy improved the most after the implementation of SSI-PjBL. This indicator-level analysis was relevant because scientific literacy consists of several competencies that may develop differently depending on the learning experience (Aqilah et al., 2025).

Table 4. Data analysis techniques

No	Technique	Purpose
1	N-Gain	Measuring improvement in scientific literacy
2	Normality test	Checking data distribution
3	Homogeneity test	Testing variance equality
4	Independent t-test/ANCOVA	Comparing differences between groups
5	Effect size (Cohen's d)	Determining the magnitude of the treatment effect

To provide a deeper understanding of the findings, the analysis was also conducted at the level of each scientific literacy indicator. This approach allowed the researcher to identify which aspects of scientific literacy improved the most as a result of the intervention, in line with recent trends in science education research (Aqilah et al., 2025).

Table 5. Scientific literacy indicators

No	Indicator	Description
1	Explaining scientific phenomena	Applying physics concepts to explain real-world phenomena
2	Evaluating and designing scientific inquiry	Assessing and proposing scientific investigations
3	Interpreting data and scientific evidence	Analyzing data, graphs, and scientific information

Table 5 presents the scientific literacy indicators used for the indicator-level analysis. These indicators were retained to clarify the specific competencies examined after the implementation of SSI-PjBL. The inclusion of this table also supports the interpretation of the findings by showing that the analysis did not only focus on overall scientific literacy scores but also on each core competency.

III. RESULTS

The results of this study are presented to examine the effectiveness of SSI-PjBL in improving students' scientific literacy in physics. The analysis focused on three main aspects: descriptive statistics, normalized gain (N-Gain), and inferential statistical testing. Descriptive statistics were used to describe students' initial and final scientific literacy scores in both groups. N-Gain analysis was used to determine the level of improvement after the learning intervention, while inferential analysis was conducted to examine whether the difference between the experimental and control groups was statistically significant. In addition, effect size analysis was used to determine the practical magnitude of the SSI-PjBL intervention.

Before the treatment was implemented, both groups were given a pretest to measure their initial scientific literacy. The pretest results showed that the experimental and control groups had relatively similar initial abilities. This similarity is important because it indicates that the two groups started from a comparable level of scientific literacy before receiving different instructional treatments. After the intervention, both groups showed improvement in their posttest scores. However, the increase in the experimental group was higher than that in the control group. This difference suggests that the SSI-PjBL approach provided a more effective learning experience than conventional instruction in supporting students' scientific literacy development.

Table 6. Descriptive statistics of scientific literacy scores

Group	N	Pretest mean	Posttest mean	Gain score
Experimental	34	52.41	81.26	28.85
Control	33	51.98	68.17	16.19

As shown in table 6, the pretest mean score of the experimental group was 52.41, while the control group obtained a pretest mean score of 51.98. The difference between these two pretest means was relatively small, indicating that students in both groups had comparable initial scientific literacy before the intervention. After the learning process, the experimental group achieved a posttest mean score of 81.26, whereas the control group achieved a posttest mean score of 68.17. The experimental group's gain score was 28.85, higher than the control group's, namely 16.19. These results indicate that students who learned through SSI-PjBL experienced greater improvement than those who learned through conventional instruction.

The descriptive results show an important pattern. Although both instructional approaches contributed to improvements in students’ learning, the increase in the experimental group was more substantial. This indicates that SSI-PjBL may have provided students with more opportunities to connect physics concepts with real-life contexts, analyze socio-scientific problems, and construct scientific explanations through project-based activities. In contrast, the lower gain in the control group suggests that conventional instruction may have improved students’ understanding but was less effective in developing broader scientific literacy competencies.

To obtain a clearer picture of the level of improvement, the normalized gain score was calculated for both groups. The N-Gain score indicates how much students’ scientific literacy improved relative to the maximum possible improvement. The results of the N-Gain analysis are presented in Table 7.

Table 7. N-gain analysis

Group	N-Gain	Category
Experimental	0.61	Moderate
Control	0.33	Low

Table 7 shows that the experimental group obtained an N-Gain score of 0.61, which falls into the moderate category. Meanwhile, the control group obtained an N-Gain score of 0.33, which falls into the low category. This finding confirms that the improvement in students’ scientific literacy was greater in the experimental group than in the control group. The moderate N-Gain in the experimental group indicates that SSI-PjBL supported meaningful progress in students’ scientific literacy. The low N-Gain in the control group indicates that conventional instruction led to improvement, but the extent of improvement was relatively limited.

The higher N-Gain in the experimental group suggests that the SSI-PjBL approach helped students engage more actively with physics concepts. Through socio-scientific issues, students were encouraged to understand physics not only as abstract knowledge but also as a tool for explaining and responding to real-world problems. Through project-based activities, students had opportunities to investigate issues, design solutions, develop products or models, and present their ideas. These learning activities are closely related to the competencies measured in scientific literacy, particularly the ability to explain phenomena, evaluate inquiry, and interpret evidence.

Inferential statistical analysis was then conducted to determine whether the difference between the experimental and control groups was statistically significant. The results of the independent-samples t-test are presented in Table 8.

Table 8. Inferential analysis (independent t-test)

Variable	t-value	Sig. (p)	Interpretation
Posttest scores	4.87	0.000	Significant difference

As shown in Table 8, the independent-samples t-test yielded a t-value of 4.87 and a significance level of 0.000. Since the p-value was less than 0.05, the difference between the experimental and control groups was statistically significant. This result indicates that the students who received SSI-PjBL instruction achieved significantly higher scientific literacy scores than students who received conventional instruction. Therefore, the statistical evidence supports the conclusion that SSI-PjBL had a significant effect on improving students' scientific literacy in physics.

The statistical significance of the posttest difference strengthens the descriptive and N-Gain findings. The experimental group not only showed a higher mean score and greater gain score but also demonstrated a statistically meaningful difference compared with the control group. This means that the improvement observed in the experimental group was unlikely to occur by chance. Instead, it was associated with the instructional treatment implemented during the learning process.

In addition to statistical significance, the effect size was calculated to determine the magnitude of the treatment effect. The effect size provides information about the practical importance of the difference between the two groups. The result is presented in Table 9.

Table 9. Effect size (Cohen's d)

Variable	Cohen's d	Category
Scientific literacy	0.92	Large

Table 9 shows that Cohen's d was 0.92, which is considered a large effect. This result indicates that the SSI-PjBL intervention had a strong practical impact on students' scientific literacy. According to Lakens (2013), an effect size above 0.80 can be considered large and practically meaningful in educational research. Therefore, the effect size result supports the claim that SSI-PjBL was not only statistically significant but also educationally meaningful.

The large effect size is an important finding because it shows that the difference between the two groups was not merely a statistical result. Instead, the SSI-PjBL approach produced a meaningful learning advantage for students in the experimental group. This suggests that integrating socio-scientific issues with project-based learning can be a powerful strategy for improving physics learning, especially when the goal is to develop scientific literacy rather than only conceptual mastery.

To provide a more detailed understanding of students' scientific literacy development, the analysis was also conducted based on each scientific literacy indicator. The indicator-level analysis is presented in Table 10.

Table 10. Improvement by scientific literacy indicators

Indicator	Pre-test	Post-test	N-gain
Explaining scientific phenomena	54.12	83.45	0.64
Evaluating and designing scientific inquiry	50.87	78.62	0.57
Interpreting data and scientific evidence	52.23	81.71	0.61

Table 10 shows that all scientific literacy indicators improved after the implementation of SSI-PjBL. The greatest improvement was found in the indicator of explaining scientific phenomena, with an N-Gain score of 0.64. This result suggests that SSI-PjBL was particularly effective in helping students use physics concepts to explain real-world phenomena. The use of socio-scientific issues may have supported this improvement, as students were exposed to contextual problems requiring scientific explanations. By connecting physics concepts to everyday issues, students were able to develop a more meaningful understanding of the concepts they learned.

The second-highest improvement was observed in the data interpretation and scientific evidence indicator, with an N-Gain score of 0.61. This finding indicates that students improved their ability to analyze data, graphs, and scientific information after participating in SSI-PjBL activities. Project-based learning activities may have contributed to this improvement because students were required to collect information, evaluate evidence, and use data to support their project decisions. These activities provided students with opportunities to practice evidence-based reasoning, an essential component of scientific literacy.

The indicator of evaluating and designing scientific inquiry also improved, with an N-Gain score of 0.57. Although this indicator showed the lowest gain among the three indicators, the improvement was still meaningful. This result indicates that students developed a better ability to assess and propose scientific investigations after participating in the SSI-PjBL intervention. However, the relatively lower gain suggests that inquiry-related competencies may require more structured guidance and longer practice. Designing scientific investigations is a complex skill because students need to identify problems, formulate questions, determine variables, plan procedures, and evaluate the quality of evidence. Therefore, additional scaffolding may be needed to strengthen this aspect of scientific literacy.

IV. DISCUSSION

The findings of this study demonstrate that SSI-PjBL produced a meaningful improvement in students' scientific literacy in physics. This improvement was reflected in the experimental group's higher posttest mean score, a moderate N-Gain score, a statistically significant between-group difference, and a large effect size. These results indicate that the intervention was not only statistically significant but also educationally meaningful. In other words, SSI-PjBL enhanced students' ability to apply physics concepts in more contextual, analytical, and evidence-based ways.

The effectiveness of SSI-PjBL can be explained by the strong relationship between scientific literacy and real-world problem contexts. Scientific literacy requires students to understand scientific concepts and use them to interpret issues that appear in everyday life. In conventional physics instruction, students often learn concepts as abstract formulas or isolated principles. Although this approach can support procedural problem-solving, it may not sufficiently help students connect physics knowledge with social, technological, and environmental problems. SSI-based learning addresses this limitation by positioning scientific concepts within authentic issues that require students to analyze evidence, evaluate alternatives, and consider the consequences of scientific decisions. This is consistent with the argument that socio-scientific learning can support functional scientific literacy by encouraging students to use science to reason and make decisions in socially relevant contexts (Zeidler et al., 2023).

The higher achievement of the experimental group also suggests that students benefited from learning physics through problems that were meaningful and relevant to their lives. When students discussed issues such as energy use, technological applications, or environmental consequences, they were required to interpret physics concepts beyond routine classroom exercises. This process may have helped students recognize that physics is not merely a collection of equations but a way of explaining and responding to real phenomena. Contextual learning is especially important in science education because students' understanding becomes stronger when new knowledge is linked to familiar, observable, and socially meaningful situations. Research on context-based science education shows that relevant contexts can improve students' motivation and conceptual engagement by helping them see the usefulness of scientific ideas in real-life situations (Bennett et al., 2007).

Another factor that may explain the improvement is the project-based structure of the intervention. PjBL provides students with opportunities to investigate problems, design solutions, develop products, and communicate their findings. These activities require active cognitive engagement rather than passive reception of information. In this study, students in the experimental group were not only exposed to socio-scientific issues but also asked to work through project stages that required inquiry, collaboration, and reflection. Such learning experiences are closely related to scientific literacy because students must formulate explanations, use evidence, and justify their ideas. Project-based learning has been shown to support deeper understanding when students are guided to investigate meaningful questions, construct artifacts, and revise their thinking through feedback and reflection (Krajcik & Shin, 2014).

The large effect size found in this study further indicates that SSI-PjBL had a strong practical impact on students' scientific literacy. A large effect size is important because it indicates that the difference between the experimental and control groups was not only statistically detectable but also meaningful in classroom practice. This finding suggests that integrating SSI and PjBL can create a stronger learning environment than conventional instruction. The combination of authentic issues and project-based activities may have created more opportunities for students to apply knowledge, discuss evidence, and construct explanations. Previous meta-analytic evidence has also indicated that project-based learning can positively affect students' science achievement when implemented with clear learning goals, structured inquiry, and appropriate teacher support (Chen & Yang, 2019).

The indicator-level results provide additional insight into how SSI-PjBL supported different dimensions of scientific literacy. The highest N-Gain was found in the ability to explain scientific phenomena. This result suggests that SSI-PjBL was particularly effective in helping students connect physics concepts with observable events and real-world issues. Through issue orientation and investigation, students were encouraged to identify scientific principles underlying social or technological problems. Through project design and presentation, they were required to explain how physics concepts could be used to understand or address those problems. This process likely strengthened their ability to construct scientific explanations. In science education, explanation is a central practice because students must connect claims, evidence, and reasoning to show how scientific ideas account for phenomena (McNeill & Krajcik, 2007).

The improvement in interpreting data and scientific evidence also indicates that SSI-PjBL supported students' evidence-based reasoning. During project activities, students needed to collect information, read data, compare sources, and use evidence to support their proposed solutions. These activities are essential because scientific literacy involves not only knowing concepts but also understanding how evidence is used to evaluate claims. In socio-scientific contexts, students are often exposed to complex information that may include uncertainty, competing explanations, or different perspectives. Therefore, students need to learn how to distinguish relevant evidence from unsupported claims. Research on socio-scientific reasoning shows that students' engagement with complex issues can improve their ability to evaluate information and justify decisions when instruction explicitly supports evidence-based argumentation (Sadler, 2004).

Although all indicators improved, the lowest N-Gain was observed in the evaluation and design of scientific inquiry. This result is important because it shows that inquiry-related competence may be more difficult to develop than the ability to explain phenomena. Designing an investigation requires students to identify researchable questions, determine variables, plan procedures, control bias, and evaluate the quality of evidence. These skills require repeated practice and explicit scaffolding. In the context of this study, SSI-PjBL provided opportunities for inquiry, but students may still have needed more structured guidance to design scientific investigations independently. This finding is consistent with research showing that inquiry learning is most effective when students receive appropriate scaffolding, as open inquiry without sufficient guidance can impose high cognitive demands on learners (Hmelo-Silver et al., 2007).

The significant difference between the experimental and control groups also highlights the limitations of conventional instruction in developing scientific literacy. Conventional physics teaching often emphasizes teacher explanation, worked examples, and formula-based exercises. While these methods may help students acquire basic content knowledge, they do not always provide enough opportunities for students to practice scientific reasoning in authentic contexts. Students may become familiar with solving numerical problems but remain less prepared to interpret evidence, evaluate scientific claims, or apply concepts to unfamiliar situations. Scientific literacy requires students to participate in practices that resemble how science is used outside the classroom, including asking questions, analyzing data, constructing explanations, and communicating arguments. Therefore, instruction that remains centered on information transmission may be insufficient for developing the full range of scientific literacy competencies.

The findings also suggest that SSI-PjBL may strengthen students' engagement and ownership of learning. Socio-scientific issues naturally invite discussion because they are connected to real problems that may affect students' communities and future lives. Project-based activities further increase engagement by giving students responsibility for producing a solution or artifact. This combination can make learning more purposeful because students understand why they are learning a concept and how it can be used. In science education, meaningful engagement is important because students are more likely to develop a durable understanding when they participate in activities that require explanation, negotiation, and reflection. Studies on project-based science learning indicate that students benefit when they are positioned as active problem solvers and when teachers provide opportunities for collaboration and public presentation of ideas (Miller & Krajcik, 2019).

From a pedagogical perspective, the results imply that SSI-PjBL can serve as a practical model for making physics learning more relevant to 21st-century educational goals. Physics topics such as energy, electricity, waves, radiation, and technology are closely related to social issues. Teachers can use these topics as entry points for designing projects that require students to apply physics knowledge to real problems. However, effective implementation requires careful planning. Teachers need to select issues that are scientifically accurate, socially relevant, and appropriate for students' cognitive levels. They also need to provide scaffolding for inquiry, data interpretation, and argumentation so that project activities do not become merely product-oriented. Without clear conceptual guidance, students may focus on completing the project artifact without developing a deep scientific understanding.

The findings of this study should also be interpreted with attention to classroom implementation. SSI-PjBL is not simply a combination of discussing issues and making projects. Its effectiveness depends on the alignment between the issue, the physics concepts, the scientific literacy indicators, and the assessment tasks. In this study, the improvement across all indicators suggests that the learning design connected these elements. Nevertheless, the lower gain in inquiry design indicates that future implementation should allocate more time to planning investigations, identifying variables, evaluating data quality, and reflecting on methodological limitations. Teachers may also use guiding questions, investigation templates, peer review, and formative feedback to strengthen students' inquiry competence.

V. CONCLUSION AND SUGGESTION

This study demonstrates that SSI-PjBL is effective in improving students' scientific literacy in physics education. Students who participated in SSI-PjBL showed greater learning gains than those who received conventional instruction, as evidenced by a higher posttest mean score, a moderate N-Gain, a statistically significant between-group difference, and a large effect size. The improvement across all scientific literacy indicators indicates that SSI-PjBL supports students' ability to explain scientific phenomena, interpret data and scientific evidence, and evaluate scientific inquiry. These findings suggest that integrating real-world socio-scientific issues with project-based activities can help students apply physics concepts more meaningfully in authentic contexts.

This study has several limitations. The sample comprised 67 eleventh-grade students from one private senior high school in Bandung, which may limit the generalizability of the findings to broader educational contexts. In addition, the study focused on a specific physics topic related to socio-scientific issues and measured students' scientific literacy within a limited intervention period. Future research should involve larger, more diverse samples; different school contexts; longer implementation periods; and various physics topics to examine the consistency and long-term impact of SSI-PjBL. Further studies may also investigate how digital tools, interdisciplinary projects, and structured inquiry scaffolding can strengthen students' scientific literacy, especially in evaluating and designing scientific inquiry. The contribution of this study lies in providing empirical evidence that SSI-PjBL can serve as a contextual, student-centered instructional approach in physics education. By connecting physics concepts to real-world issues and project-based learning, this study supports the development of more relevant physics instruction aligned with the goals of 21st-century science education.

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