JURNAL BIOEDUIN

p-ISSN : 2338-7173
e- ISSN : 2615-0417
(Agustus 2026), Vol. (16), No. (2)

# Problem-Based Learning (PBL) Model Integrated with Social-Scientific Issues (SSI): Enhancing Students' Environmental Literacy

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## Abstract

Global environmental issues are now a major focus worldwide. In light of these challenges, environmental literacy is increasingly recognized as an essential 21st-century competency that should be developed through education. One approach to achieving this is to implement a Problem-Based Learning model integrated with Socio-Scientific Issues. The purpose of this study is to analyze the influence of the SSI-integrated PBL model on students' environmental literacy. The study employed a quasi-experimental research design involving a nonequivalent control group. Purposive sampling was employed to select students from SMAN 3 Temanggung, with Class X6 as the control group and Class X8 as the experimental group, each consisting of 36 students. Data collection instruments consisted of 18 multiple-choice questions and 23 Likert-scale items. Statistical data analysis employed an ANCOVA test, preceded by normality and homogeneity prerequisite tests. The findings demonstrate that the integration of SSI into the PBL model has a significant impact on students' environmental literacy, with a significance value of 0.000 ($p < 0.05$). The result indicates a substantial difference in environmental literacy between the experimental group and control group. Presenting real-world environmental issues through this innovative model effectively helps the students realize the importance of environmental literacy. This study provides valuable insights for educators implementing the SSI-integrated PBL model as an alternative method to improve environmental literacy, particularly in secondary biology education.

**Keywords:** environmental change, environmental literacy, problem-based learning model, socio-scientific issues

## INTRODUCTION

Environmental issues are a global concern that has become a major focus worldwide (Ferronato & Torretta, 2019; Nash et al., 2019; Patrianti et al., 2020), triggered by various human activities and their interaction with the environment (Pangestu et al., 2023). The World Economic Forum's (WEF) 2024 Global Risks Report indicates that environmental risks rank first, with a score of 66%, as a global risk in 2024. This reflects the high threat to ecosystem sustainability posed by human activities, such as the overexploitation of natural resources and waste disposal leading to pollution, as well as environmental imbalances (Pratama et al., 2020). The quality of the environment is influenced by people's awareness of the need to preserve it to support ecosystem sustainability (Jadda et al., 2024). Such awareness will drive conservation efforts and prevent further damage (Daniyarti, 2022), while also addressing these issues through environmentally friendly behavior and sound environmental literacy (Kurniati et al., 2021).

Environmental literacy is an individual's insight and awareness of environmental conditions, enabling them to respond to, commit to, pay attention to, and recognize these conditions to help reduce or address environmental issues (Nasution, 2021). Environmental literacy empowers individuals to understand and interpret environmental conditions, enabling them to make informed decisions to

p-ISSN : 2338-7173
e- ISSN : 2615-0417
(Agustus 2026), Vol. (16), No. (2)

protect, improve, and maintain environmental quality (Holdaway, 1979). A study by Miterianifa & Mawarni (2024) revealed that environmental literacy has the potential to develop environmental knowledge and awareness. An individual's environmental literacy can be evaluated based on four key indicators: insight, cognitive abilities, environmental awareness, and responsible environmental behavior (McBeth et al., 2008; McBeth & Volk, 2009; Mcbeth et al., 2011).

Environmental literacy is important to instill in every individual in order to shape human character in the 21st century (Ramadhana et al., 2022). Indriyani et al. (2021) noted in their study that environmental literacy is part of 21st-century learning topics that hold great potential for addressing the demands and challenges of this era, as outlined in the P21 Framework for 21st-Century Learning. Incorporating environmental literacy into the learning development helps students comprehend and implement these understandings in their everyday lives, while also contributing to preventing and addressing environmental degradation (Siddiq et al., 2020; Indrawan et al., 2022). This ability can be developed through materials on environmental change, particularly regarding pollution and its management. These topics are closely related to the principles of environmental literacy, so they are mutually supportive and aligned (Nariswari et al., 2022).

Improving students' environmental literacy can be attained through the implementation of the Problem-Based Learning (PBL) model, which motivates students to actively participate in addressing various issues, including social and environmental problems within their surroundings (Adiwiguna et al., 2019; Kurniawan et al., 2019; Zulfah et al., 2024). Students' ability to address environmental problems will improve as their environmental literacy increases, reinforced through the implementation of problem-based learning (PBL) (Adela et al., 2018). Through this approach, students take an active role in the learning process by working collaboratively to address various real-world problems within their surrounding environment (Hendriana et al., 2018; Hartina & Permana, 2022). Several studies have demonstrated a connection between students' environmental literacy and their capacity to address environmental issues. (Siddiq et al., 2020; Santoso et al., 2021; Anggraini et al., 2022; Idris et al., 2022).

The Problem-Based Learning (PBL) model emphasizes solving real-world problems related to daily life (Widiasworo, 2018) so that students acquire knowledge through direct experience and problem-solving (Arends, 2008; Choirunisa et al., 2023). This model is suitable for learning situations that require students to face issues, find solutions, and collaboratively seek ways to resolve issues (Hartina & Permana, 2022). Structurally, The PBL model comprises five stages: introducing students to the problem, organizing them for learning, facilitating individual and group investigations, developing and presenting solutions or products, and analyzing and evaluating the problem-solving process. (Arends, 2012). Each of these phases contributes to enhancing students' environmental literacy. The application of PBL can improve environmental literacy by encouraging students to actively solve problems, including social and environmental issues in their surroundings (Aufa et al., 2021; Seibert, 2021; Afelia et al., 2023).

The PBL model can be integrated with Socio-Scientific Issues (SSI) to help students better understand learning that is relevant to real life. Socio-Scientific Issues (SSI) refer to social issues that are connected to scientific concepts and involve multiple possible solutions rather than a single definitive answer (Ratcliffe & Grace, 2003; Wilsa et al., 2017). Through SSI-integrated PBL, students are encouraged to investigate contemporary issues that combine social, ethical, environmental, and scientific aspects so that they not only address problems but also recognize their social, ethical, and scientific implications (Zahra et al., 2021; Prismayadi & Choirunnisa, 2024). The SSI approach is

p-ISSN : 2338-7173
e- ISSN : 2615-0417
(Agustus 2026), Vol. (16), No. (2)

particularly well-suited for biology instruction because it bridges real-world problems in the social environment with scientific concepts (Zeidler & Nichols, 2009). Among the socio-scientific issues addressed in this material are the controversy surrounding the development of the *Ibu Kota Nusantara* (IKN) in Kalimantan and its impact on the preservation of tropical rainforests as the "*paru-paru dunia*" as well as the pros and cons of the plastic bag ban, the culture of "thrifting" (secondhand clothing), and the threat of textile waste accumulation in local communities. Through these issues, students are encouraged to analyze problems from ecological and socio-economic perspectives before making ethical environmental decisions based on scientific data.

Previous research by Anggraini et al., (2022), Anwar et al., (2023), Bidahyani et al., (2024), dan Zulfah et al., (2024) shows that the PBL model is effective in improving high school students' environmental literacy. At the same time, studies by Aisy et al. (2024) dan Zamri et al. (2025) have begun integrating the PBL model with the SSI approach to develop critical thinking, creativity, collaboration, and problem-solving skills. However, these studies still have gaps. PBL-based learning aimed at improving environmental literacy focuses solely on ecological theory and neglects students' capacity to make ethical decisions when confronted with real-world issues in society (Siddiq et al., 2020). Implementing the PBL model without integrating it with socio-scientific issues makes the discussion of problems too theoretical. Therefore, this study offers a novel approach: the application of the Problem-Based Learning model integrated with Socio-Scientific Issues as a learning strategy to enhance students' environmental literacy in relation to environmental changes. Therefore, this study intends to examine the impact of the Problem-Based Learning model integrated with Socio-Scientific Issues on students' environmental literacy.

## RESEARCH METHOD

This study adopted a quantitative approach with a quasi-experimental method using a nonequivalent control group design, as shown in Table 1.

**Table 1.** Research Design-Nonequivalent Control Group Design

| Class | Pretest | Treatment | Posttest |
|---|---|---|---|
| Experimental (E) | $O_1$ | X | $O_2$ |
| Control (K) | $O_3$ | - | $O_4$ |

(Source: Sugiyono, 2012)

Notes:
$O_1$: Pretest for the experimental class
$O_2$: Posttest for the experimental class
$O_3$: Pretest for the control class
$O_4$: Posttest for the control class
X : Treatment using the SSI integrated PBL model

The study population comprised 320 tenth-grade students at *SMA Negeri 3 Temanggung*. The study sample comprised two classes with the same number of students: Class X6 as the control group and Class X8 as the experimental group. Each class consisted of 36 students, with a balanced ratio of 18 boys and 18 girls, all aged 15–16 years. The study employed a nonprobability sampling technique using purposive sampling based on predetermined considerations (Sugiyono, 2019). The control class received instruction using the Discovery Learning model, which is commonly applied by teachers at the school. In contrast, the experimental class implemented the Problem-Based Learning model integrated with Socio-Scientific Issues.

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e- ISSN : 2615-0417
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The data in this study were collected using both test and non-test techniques. The test instrument comprised multiple-choice questions intended to assess students' comprehension and cognitive skills as indicators of environmental literacy. Meanwhile, the non-test instruments included a Likert-scale questionnaire to assess environmental literacy indicators and another Likert-scale questionnaire to evaluate environmental concern and environmentally responsible behavior. All of these data collection instruments were adapted and developed based on environmental literacy indicators derived from the National Environmental Literacy Assessment (NELA) (Mcbeth et al., 2011).

The instruments were pilot-tested before data collection to ensure their suitability. Validity was determined using the Pearson Product-Moment correlation coefficient, while reliability was evaluated using Cronbach's Alpha. (Sugiyono, 2017). The results of these tests are presented in Table 2.

**Table 2.** Results of the Validity and Reliability Tests for the Environmental Literacy Instrument

| Indicator | Sub-Indicator | Total Number of Items | Valid Items (Item Number) | Validity Coefficient Range ($r_{hitung}$) | Reliability Coefficient (α) | Interpretation |
|---|---|---|---|---|---|---|
| Knowledge | Basic concepts of ecology | 17 | 12 (1, 3, 4, 5, 6, 9, 12, 13, 14, 15, 16, 17) | 0.334 – 0.664 | | |
| Cognitive Skills | Identifying environmental issues | 3 | 1 (26) | 0.364 | 0.823 | Very High |
| | Analyzing environmental issues | 6 | 4 (22, 23, 24, 25) | 0.486 – 0.674 | | |
| | Strategies for addressing environmental issues | 1 | 1 (27) | 0.368 | | |
| Environmental Awareness | Verbal commitment | 10 | 7 (1, 2, 3, 6, 7, 8, 9) | 0.344 – 0.507 | | |
| | Environmental awareness | 8 | 3 (11, 14, 17) | 0.431 – 0.459 | 0.714 | High |
| | Feelings toward the environment | 2 | 2 (19, 20) | 0.346 – 0.353 | | |
| Environmentally Responsible Behavior | Concrete actions (pro-environmental behavior) | 14 | 11 (23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 34) | 0.342 – 0.537 | | |

Based on Table 2, all instrument indicators deemed valid had validity coefficients ($r_{hitung}$) exceeding the critical value $r_{tabel}$ at a 5% significance level with N = 36, where $r_{tabel}$ = 0.329. Furthermore, the Cronbach's Alpha (α) reliability index for all indicators was above the minimum threshold of 0.60; therefore, this instrument was deemed valid, reliable, and appropriate for measuring students' environmental literacy (Arikunto, 2010).

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e- ISSN : 2615-0417
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After the research instruments were deemed eligible, the next step was to implement the learning process in the experimental group using the Problem-Based Learning model integrated with Socio-Scientific Issues through five main stages presented in Table 3.

**Table 3.** Syntax for Problem-Based Learning Model

| Phase | Teacher Behavior |
|---|---|
| Introduce students to the problem | The teacher explains the learning objectives, outlines essential logistical requirements, and encourages students to actively engage in problem-solving activities. |
| Organize students for learning | The teacher assists students in defining and organizing learning tasks related to the problem. |
| Facilitate independent and group investigation | The teacher facilitates students in collecting relevant information, conducting experiments, and seeking explanations and appropriate solutions. |
| Develop and present artifacts and exhibits | The teacher guides students in planning and developing appropriate artifacts, such as reports, videos, and models, and facilitates the presentation of their work to others. |
| Analyze and evaluate the problem-solving process | The teacher guides students in reflecting on their investigations and evaluating the processes they employed. |

(Source: Arends, 2012)

The environmental literacy data collected after implementing the learning activities were then analyzed using statistical data analysis techniques. The statistical analysis commenced with preliminary tests, namely the Kolmogorov-Smirnov test for normality and Levene's test for homogeneity of variances. (Usmadi, 2020). The decision criterion for these two prerequisite tests is that a significance value greater than 0.05 indicates that the research data are normally distributed and have homogeneous variances. After meeting the prerequisites for parametric analysis, Hypothesis testing was performed using Analysis of Covariance (ANCOVA) at a 5% significance level with SPSS version 25. The decision criterion states that when the significance value is less than 0.05, $H_0$ is rejected and $H_a$ is accepted (Arikunto, 2013).

The development in students' environmental proficiency after the intervention was analyzed using the N-Gain test to assess the increase from pretest to posttest. The N-Gain scores were determined by calculating the difference between the pretest and posttest scores for each sample group using the formula proposed by Meltzer (2002):

$$\text{N} - \text{Gain} = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Ideal Maximum Score} - \text{Pretest Score}}$$

(Source: Isnaniah & Imamuddin, 2020)

The gain values obtained were interpreted according to the N-Gain index classification proposed by Hake (1999) , as presented in Table 4.

**Table 4.** Interpretation of N-Gain

| N-Gain Index | Interpretation |
|---|---|
| N-Gain ≥ 0.7 | High |
| 0.3 ≤ N-Gain < 0.7 | Medium |
| N-Gain < 0.3 | Low |

(Source: Isnaniah & Imamuddin, 2020)

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e- ISSN : 2615-0417
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## RESULT AND DISCUSSION

The findings of the study indicate a difference in pretest and posttest environmental literacy grades between the control class and the experimental class that implemented the PBL model integrated with SSI. The experimental group showed a greater average score increase compared to the control group. Table 5 presents the descriptive statistical results, including the minimum, maximum, mean, and standard deviation for both sample groups.

**Table 5.** Results of the Descriptive Statistical Analysis of Students' Environmental Literacy

| Class | Mean | Standard Deviation | Min Score | Max Score |
|---|---|---|---|---|
| Control Class Pretest | 59.03 | 2.396 | 55 | 65 |
| Control Class Posttest | 76.53 | 4.299 | 63 | 84 |
| Experimental Class Pretest | 59.47 | 3.149 | 53 | 67 |
| Experimental Class Posttest | 81.11 | 3.022 | 74 | 84 |

As presented in Table 5, the average pretest and posttest points for environmental literacy in the experimental group were higher than those in the control class. On the other hand, the experimental group exhibited a lower standard deviation in the posttest scores than in the pretest scores. Conversely, in the control class, the pretest scores had a lower standard deviation than the posttest scores. These findings indicate that the data distribution for the control class's pretest and the experimental group's posttest was more homogeneous and clustered closer to the mean.

The subsequent stage in the data analysis for this paper is to conduct inferential statistical tests to test the research hypotheses. The analysis began with prerequisite testing, including the Kolmogorov-Smirnov test for normality, Levene's test for homogeneity of variances, and the test for homogeneity of regression slopes. This step ensured that the environmental literacy data from both sample groups met the assumptions of parametric statistical analysis. The findings of the preliminary tests are shown in Table 6.

**Table 6.** Findings of the Environmental Literacy Prerequisite Test for Students

| Type of Analysis | Component Tested | Statistical Score/ F | Sig. | Conclusion |
|---|---|---|---|---|
| Normality Test (Kolmogorov-Smirnov) | Pretest Control Class | 0.128 | 0.144 | Normally Distributed (sig) > 0.05 |
| | Posttest Control Class | 0.127 | 0.151 | |
| | Pretest Experimental Class | 0.131 | 0.125 | |
| | Posttest Experimental Class | 0.126 | 0.162 | |
| Homogeneity Test (Levene's Test) | Variance of Sample Group Data | 2.948 | 0.090 | Homogeneous Variance (sig) > 0.05 |
| Homogeneity of Regression Slopes | Class X Pretest Interaction | 3.110 | 0.082 | Homogeneous (sig) > 0.05 |

Based on Table 6, the normality test outcomes indicate that the data from the experimental and control groups had significance values exceeding 0.05, indicating that the data were normally distributed. Furthermore, Levene's test for homogeneity of variances produced a statistic of 2.948 with a significance value of 0.090, which exceeded 0.05, indicating that the variances between the two

p-ISSN : 2338-7173
e- ISSN : 2615-0417
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groups were homogeneous. Additionally, the test for homogeneity of regression slopes for the Class X Pretest interaction yielded an F statistic of 3.110 with a significance value of 0.082, which was greater than 0.05. This result indicates that the regression lines for the two groups were homogeneous or parallel. The fulfillment of these three assumptions indicates that data analysis can proceed using parametric statistics.

After meeting the prerequisite assumptions, hypothesis testing was performed using Analysis of Covariance (ANCOVA) at a 5% significance level ($\alpha = 0.05$). This analysis tested the impact of the SSI-integrated PBL model on students' environmental literacy while controlling for pretest scores as a covariate. Table 7 presents the ANCOVA results.

**Table 7.** Results of the ANCOVA Test on Environmental Literacy

| Source | Type II Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Pretest | 16.435 | 1 | 16.435 | 1.194 | 0.278 | 0.017 |
| Class | 390.885 | 1 | 390.885 | 28.388 | 0.000 | 0.291 |
| Error | 950.093 | 69 | 13.769 | | | |

Based on Table 7, the F-value for the treatment was 28.388 with a significance level of 0.000, which is below 0.05. This value reveals that $H_0$ is rejected and $H_a$ is accepted, demonstrating an important difference in students' environmental literacy between the experimental and control groups after controlling for pretest scores. Thus, the application of the Problem-Based Learning (PBL) model integrated with Social-Scientific Issues (SSI) illustrates an effect on students' environmental literacy.

In addition, the effect size analysis produced a Partial Eta Squared ($\eta_p^2$) value of 0.291. Based on the reference criteria established by Cohen (1988), a value of $\eta_p^2 \geq 0.14$ falls within the large effect category. These values show that implementing the PBL model integrated with SSI contributed 29.1% to students' environmental literacy outcomes. At the same time, the remainder was affected by other causes beyond the learning model. The magnitude of this input confirms that presenting contextual socio-scientific issues within the PBL model effectively and significantly enhances students' critical reasoning skills and ecological understanding. This finding is in line with research conducted by Anwar et al. (2023) and Naibaho et al. (2025) , which indicated that PBL-based learning can influence students' environmental literacy.

In practice, the experimental group performed better than the control group because the PBL model fosters students to develop critical thinking competence through the investigation of real-life issues (Wilsa et al., 2017). Its effectiveness increases when integrated with Socio-Scientific Issues (SSI), which contextually present scientific and social issues (Zeidler et al., 2019) and are closely tied to everyday life (Naibaho et al., 2025). This combination of the PBL-SSI model empowers students to comprehend environmental problems comprehensively from social, economic, and cultural perspectives (Dalaila et al., 2022), while also fostering independence in finding solutions through problem-solving (Winoto & Prasetyo, 2020).

In contrast, in the control group, the Discovery Learning model tends to focus on the gradual discovery of theoretical concepts without strong demands for critical thinking (Gani et al., 2021). Without engagement with real-world problems, students in the control class often struggle to formulate hypotheses, are less responsive to surrounding issues, and fail to develop their critical thinking skills to their full potential (Sari et al., 2021). Consequently, this situation results in the

p-ISSN : 2338-7173
e- ISSN : 2615-0417
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learning model used in the control class being less effective in fostering students' environmental literacy compared to the experimental class (Anwar et al., 2023).

After confirming the presence of a significant effect through an ANCOVA test, the analysis continued by measuring the extent of enhancement in students' environmental proficiency using the N-Gain test. This analysis was conducted to determine the extent to which the performance of each class group had improved. In this paper, students' environmental literacy was measured rely on four main factors: knowledge, cognitive skills, consideration for the environment, and environmentally responsible conduct (McBeth et al., 2008; McBeth & Volk, 2009; Mcbeth et al., 2011). These four indicators were developed through a problem-solving-based learning process that fully integrates cognitive, affective, and psychomotor aspects (Siddiq et al., 2020). The activities in this learning model serve as the primary stimuli influencing students' achievement on each environmental literacy indicator. Therefore, the N-Gain analysis for each indicator in both classes serves as a benchmark to test the effectiveness of the implemented model, while also identifying which indicators are strengths and which remain challenges in this study. The N-Gain values calculated for each environmental literacy indicator in the control and experimental groups are shown in Table 8.

**Table 8.** Students' Environmental Literacy N-Gain Scores

| Indicator | Control Class | | Experimental Class | |
|---|---|---|---|---|
| | N-Gain Score | Interpretation | N-Gain Score | Interpretation |
| Knowledge | 0.67 | Medium | 0.90 | High |
| Cognitive Skills | 0.62 | Medium | 0.75 | High |
| Environmental Awareness | 0.17 | Low | 0.15 | Low |
| Environmentally Responsible Behavior | 0.27 | Low | 0.21 | Low |

Based on Table 8, the N-Gain results show that in the control group, the indicators for understanding and cognitive abilities met the "moderate" criteria. In contrast, the indicators for environmental concern and environmentally responsible behavior fell into the "low" criteria. In contrast, the experimental group demonstrated a more significant enhancement, meeting the "high" criteria for the indicators of understanding and cognitive skills. However, the indicators of environmental concern and environmentally responsible behavior remained in the "low" criteria.

A more in-depth analysis of each indicator shows that the knowledge indicator yielded the highest score contrasted to the other indicators, in the control class (0.67) and in the experimental class (0.90), even though the two classes were evaluated using different criteria. This occurred because, for the knowledge indicator, the majority of students were able to answer the assessment instrument correctly. According to Coyle (2005), environmental knowledge indicators focus on students' understanding of basic ecological concepts, environmental processes, and their impacts on life. The highest N-Gain scores on the knowledge indicator align with Bloom's Taxonomy as revised by Anderson and Krathwohl (2001). Within this framework, the ability to recall and understand factual and conceptual knowledge serves as the foundation—or the most basic cognitive dimension—before students achieve higher-order thinking skills (Huseng et al., 2025). Through active PBL-based learning integrated with SSI, which requires students to solve real-world problems actively and critically (Fadilla & Ulfa, 2025), this basic cognitive structure is most rapidly stimulated and most responsive to short-term classroom interventions. The discovery is also in line with research conducted by Ulfa Zahrani et al. (2024), which showed that knowledge indicators exhibited the highest level of improvement compared to other indicators.
The second indicator cognitive skills ranked second among the environmental literacy indicators showing the highest improvement, consistent with the findings of Setianti (2024) study. This study

p-ISSN : 2338-7173
e- ISSN : 2615-0417
(Agustus 2026), Vol. (16), No. (2)

yielded N-Gain values of 0.62 in the control and 0.75 in the experimental group. According to Morrone (2001), cognitive skills in environmental literacy include the capacity to inspect, evaluate, and appropriately address environmental problems. These findings align with Social Constructivism and the concept of Higher-Order Thinking Skills (HOTS) in Bloom's Taxonomy, where higher-order thinking skills can only develop optimally once students have a solid foundation of knowledge (Bloom et al., 1956). Lev Vygotsky emphasized that students' cognitive development is greatly influenced by social context and interactions with others (Vygotsky, 1978). In classroom implementation, cognitive skills train students to identify facts and plan strategies for investigating issues, thereby helping them become accustomed to thinking innovatively when formulating practical solutions to the problems presented (Ristiana, 2021). Through group investigations and peer scaffolding within this SSI-integrated PBL model, students' analytical and evaluative abilities are gradually stimulated to a higher level (Azis et al., 2025).

The third and fourth indicators, environmental concern and environmentally responsible behavior, are two closely interrelated aspects. Theoretically, a sense of environmental concern that develops within students will motivate them to engage in environmentally responsible practices, as the combination of these two factors is a strong predictor of behavior (Mulati & Kuswati, 2022). Based on the N-Gain analysis, the attitude indicator ranked lowest in both classes, at 0.15 in the experimental group and 0.17 in the control group. Meanwhile, the behavior factor was slightly higher, though still within the low range, with scores of 0.21 in the experimental group and 0.27 in the control group. According to Milfont & Duckitt (2010), the attitude indicator measures the development of students' concern and responsibility toward environmental issues, whereas the behavioral indicator encompasses actual conservation practices such as recycling and energy conservation (Larson et al., 2015).

The low level of improvement in these two affective aspects compared to the cognitive domain can be explained using the Krathwohl et al. (1964) taxonomy. The affective domain—which comprises emotions, values, motivation, and manners—takes considerable time to internalize and develop toward maturity, a process that must be preceded by knowledge acquisition. In the short term, PBL learning integrated with SSI is more effective at stimulating knowledge acquisition, with effects that can be felt immediately. Conversely, changes in attitude and the adoption of environmentally friendly behaviors require a habit-forming period that varies significantly, ranging from 18 to 254 days (Lally et al., 2010).

The dynamics and variations in effectiveness among these indicators highlight the importance of assessing environmental literacy achievements not only individually but also holistically. Therefore, as a next step in the comparison, this analysis focuses on examining the overall average N-Gain scores to compare the effectiveness of improving students' environmental literacy between the two class groups. The findings of the total N-Gain analysis are displayed in Table 9.

**Table 9.** Mean N-Gain Results

| Class | Mean Score | | N-Gain | Interpretation |
|---|---|---|---|---|
| | Pretest | Posttest | | |
| Control | 59.03 | 76.53 | 0.42 | Medium |
| Experimental | 59.47 | 81.11 | 0.53 | Medium |

Based on Table 9, the median N-Gain score for environmental literacy in the experimental group was 0.53, while that of the control class was 0.42. Although both classes fell under the same effectiveness criterion, namely "Medium," the average N-Gain score of the experimental class was quantitatively

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e- ISSN : 2615-0417
(Agustus 2026), Vol. (16), No. (2)

greater than that of the control class. This difference in scores confirms that the Problem-Based Learning (PBL) intervention integrated with Socio-Scientific Issues (SSI) is more effective in improving students' overall environmental literacy.

This total N-Gain score also serves as supporting evidence that reinforces the findings of the previous hypothesis test. As a method for measuring the relative change between pretest and posttest scores, this N-Gain score demonstrates the effectiveness of the learning model in making a tangible contribution to improving students' understanding (Safitri & Sukardi, 2025). The consistent relationship between the hypothesis test results and the magnitude of the N-Gain values confirms that the superior performance of the experimental class was not due to chance but rather to the effectiveness of the integrated SSI-PBL model, which was consistently implemented throughout the learning mechanism.

In practical terms, the findings of this study offer a tangible contribution to biology educators by supporting the implementation of the SSI-integrated PBL model as an effective alternative learning strategy. By exploring contextual socio-scientific issues related to environmental change, this model offers an interactive and engaging learning experience as students delve into ecological issues. For schools, the outcomes of this research can serve as a reference for designing learning examples that develop students' character by equipping them with environmental literacy and the ability to make ethical decisions based on scientific data.

Despite its positive implications, this study has several limitations. First, biology classes were scheduled for the last period of each day, when classroom conditions tend to be less conducive due to declining student concentration and stamina. Second, this study was conducted over a comparatively limited period of time—only four weeks—making it impossible to evaluate the long-term impact of the implemented learning example on students' environmental literacy. Finally, the data obtained through the questionnaire may not fully represent actual field conditions because it is influenced by subjective variations, such as differences in perception, ways of thinking, and levels of understanding among students, as well as the degree of honesty in completing the self-assessment instrument.

## CONCLUSION

Based on the outcomes of the data analysis, it is concluded that the implementation of the Problem-Based Learning (PBL) model integrated with Socio-Scientific Issues (SSI) has a considerable impact on students' environmental literacy. The greatest improvement was observed in the indicators of understanding and cognitive abilities (high category), meanwhile, the indicators of environmental concern and responsible behavior showed the least improvement (low category). This learning approach has proven effective in transferring conceptual understanding and stimulating students' analytical reasoning regarding environmental issues. However, it has not yet been able to profoundly transform the affective domain and behavioral automation within the short duration of the intervention.

Considering the limitations identified in this study, a few suggestions are proposed for forthcoming research. First, next studies should be conducted during the early class periods to anticipate the decline in concentration and student burnout that often occurs during the last periods of the day. Second, to objectively evaluate success in the affective and behavioral domains, it is recommended to implement learning interventions over a longer period so that the process of habit formation among

p-ISSN : 2338-7173
e- ISSN : 2615-0417
(Agustus 2026), Vol. (16), No. (2)

students can be thoroughly documented. Finally, future researchers are recommended to triangulate data collection methods by combining self-assessment questionnaires with field observation sheets of actual behavior or peer assessment to minimize the bias of student subjectivity.

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