

STEM-PjBL based on the issue of clean water availability through filtration using banana peel activated carbon to improve students' environmental literacy

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Abstract

STEM-PjBL based on the issue of clean water availability through filtration using banana peel activated carbon to improve students' environmental literacy. Environmental issues in science learning are often presented conceptually, limiting students' opportunities to engage with authentic environmental problems. This study aimed to examine the implementation of STEM-Project Based Learning (STEM-PjBL) through a banana peel activated carbon filtration project to improve students' environmental literacy. A quasi-experimental method with a non-equivalent control group design was employed involving 67 Grade IX students at SMP BPPI Baleendah, Indonesia, comprising 33 students in the experimental class and 34 students in the control class. Participants were selected purposively based on comparable academic characteristics, and baseline equivalence was examined using environmental literacy pretest scores. The experimental class received STEM-PjBL through the stages of reflection, research, discovery, application, and communication, while the control class received conventional learning. Data were collected using a 20-item environmental literacy test covering environmental knowledge, cognitive skills, environmental affect, and environmentally responsible behavior. Data were analyzed using descriptive statistics, an independent-samples t-test, normalized gain (N-gain), and Cohen's d. The experimental class obtained a higher N-gain (0.727) than the control class (0.392), with a significant posttest difference ($p < 0.001$) and a Cohen's d of 2.09. Improvements were observed across all four dimensions, particularly environmental affect and environmentally responsible behavior. These findings indicate that contextualized STEM-PjBL can support environmental literacy development through authentic environmental problem solving.

Keywords: STEM-PjBL; Environmental Literacy; Clean Water Quality; Banana Peel Activated Carbon; Science Education

Introduction

Science learning is oriented not only toward the mastery of scientific concepts and facts but also toward the development of scientific reasoning, problem solving skills, and students' ability to respond to environmental problems. However, environmental education can remain disconnected from students' everyday experiences when learning emphasizes textual knowledge without sufficient opportunities to engage with real world problems. A recent systematic review of environmental literacy research in Indonesia reported that effective environmental education needs to connect classroom learning with real-world applications and meaningful interactions with the surrounding environment (Larasaty et al., 2024). Such a connection is important because environmental problems are complex and require students to use scientific knowledge to interpret conditions, evaluate alternatives, and consider appropriate environmental actions (Cintiati et al., 2024)

Environmental literacy therefore represents an important competency in contemporary science education. It encompasses not only environmental knowledge but also cognitive skills for identifying and analyzing environmental problems, affective dimensions related to environmental concern and sensitivity, and environmentally responsible behavior (Ardoin et al., 2020; McBeth & Volk, 2010). These dimensions indicate that environmental literacy extends beyond knowing environmental concepts; students also need opportunities to interpret evidence, evaluate possible solutions, develop concern for environmental conditions, and consider

responsible actions (Amaliati et al., 2024). Within Education for Sustainable Development (ESD), these competencies are relevant to preparing students to participate in addressing environmental challenges and supporting sustainable development (UNESCO, 2023).

Nevertheless, developing environmental literacy requires learning experiences that explicitly connect environmental concepts with authentic problems. Previous research has demonstrated that project-based and STEM-integrated learning can provide such experiences (Arpan et al., 2025; Fajarwati et al., 2025). For example, Baran et al. (2021) investigated project-based STEM learning using waste materials and reported improvements in several twenty-first-century skills, including collaboration, problem solving, creativity, and environmental awareness. However, their study used a pre-experimental design with a relatively small sample and focused primarily on twenty-first-century skills rather than a multidimensional environmental literacy framework. Similarly, a meta-analysis by Kwon and Lee (2025) found a substantial positive effect of STEM project-based learning on students' creativity, but the outcome examined was creativity rather than environmental literacy. These findings support the potential of STEM-PjBL for active and contextual learning, while also indicating that its application to environmental literacy requires further investigation in specific environmental contexts.

More directly, Pertiwi et al. (2024) examined STEM-PjBL and environmental literacy using a quasi-experimental non-equivalent pretest-posttest control group design. Their study reported improvements in environmental literacy encompassing environmental knowledge, cognitive skills, attitudes, and behavior toward environmental problems. However, the intervention was implemented in the context of environmental pollution and compared STEM-PjBL with conventional PjBL; it did not specifically employ a clean water filtration project using banana peel derived activated carbon. Thus, although previous research has established the potential of STEM-PjBL to support environmental literacy, the use of a locally relevant water quality problem combined with biomass based activated carbon as a project context represents a different learning context that warrants further examination (Agustina et al., 2026).

The issue of clean water quality provides a relevant context for this purpose because it can be directly observed in students' surrounding environments. Preliminary field observations in the research context indicated that water in some students' residential areas appeared cloudy and yellowish. These observable conditions provided a meaningful environmental problem through which students could investigate water quality, identify possible causes, and consider appropriate treatment solutions. Rather than presenting water pollution only as a conceptual topic, the issue can be transformed into an authentic learning problem that requires students to investigate scientific information, develop a solution, test its performance, and evaluate the results.

STEM-PjBL provides a suitable instructional framework for organizing these learning experiences. The Laboy-Rush framework consists of five interconnected stages: reflection, research, discovery, application, and communication. These stages provide opportunities for students to move from recognizing a real-world problem toward investigating relevant scientific concepts, designing a solution, testing the developed product, analyzing evidence, and communicating the results. In relation to environmental literacy, the learning process can provide opportunities to develop environmental knowledge through investigation of water pollution, filtration, and adsorption; cognitive skills through problem analysis, design, measurement, and interpretation of evidence; environmental affect through direct engagement with an environmental problem; and environmentally responsible behavior through consideration and evaluation of practical environmental solutions (Laboy-Rush, 2011; McBeth & Volk, 2010). Importantly, these relationships represent the learning opportunities provided by the integrated project, rather than evidence that any individual STEM-PjBL stage directly causes a particular dimension of environmental literacy.

The use of banana peel as a project material further strengthens the contextual and sustainability dimensions of the learning. Banana peel is an abundant biomass waste material that can be processed into carbon based adsorbent materials. Recent studies have demonstrated the potential of banana-peel-derived activated carbon for adsorption applications, including the removal of metal ions and other substances from aqueous systems (Widi et al., 2025). Research on banana peel based filtration has also demonstrated its potential as a natural filtration medium and has evaluated changes in water pH, TDS, and clarity (Sihite et al.,

2023). Consequently, a filtration project using banana peel activated carbon can connect several scientific concepts, including water pollution, material properties, adsorption, filtration, biomass utilization, and water-quality measurement, while simultaneously introducing students to the possibility of transforming organic waste into a functional environmental material (Arpan et al., 2025; Sukmawardani et al., 2024; Suryana et al., 2024).

The combination of these elements provides the specific research gap addressed in the present study. Previous studies have established that STEM-PjBL can support environmental literacy and other twenty-first-century competencies, while studies on banana peel derived carbon have demonstrated its potential for water treatment related applications. However, based on the studies considered in this research, the integration of STEM-PjBL, a clean water environmental issue, and a filtration project using banana-peel activated carbon as a context for developing students' multidimensional environmental literacy has not been sufficiently examined. The present study therefore aimed to examine the effect of STEM-PjBL based on the issue of clean water availability through a filtration project using banana peel activated carbon on students' environmental literacy, encompassing environmental knowledge, cognitive skills, environmental affect, and environmentally responsible behavior.

Method

Research Design

This study employed a quasi-experimental research method with a non-equivalent control group design. This design is used when researchers cannot randomly assign individual subjects but instead use pre-existing groups (Creswell & Creswell, 2018). The study involved two groups: an experimental class that received STEM-PjBL through a filtration project using banana peel activated carbon and a control class that received conventional learning. The research design is presented in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental class	O ₁	STEM-PjBL	O ₂
Control class	O ₃	Conventional Learning	O ₄

Notes:

O₁: environmental literacy pretest in the experimental class

O₂: environmental literacy posttest in the experimental class

O₃: environmental literacy pretest in the control class

O₄: environmental literacy posttest in the control class

Research Participants

The study involved Grade IX students at SMP BPPI Baleendah, Indonesia, who participated in environmental science learning focusing on clean water quality issues. The sample was selected using purposive sampling based on the equivalence of academic characteristics and the recommendation of the subject teacher (Fraenkel et al., 2019). The participants were 67 ninth-grade students (aged 14–15 years) from SMP BPPI Baleendah, Indonesia. The experimental class consisted of 33 students (16 males and 17 females), while the control class consisted of 34 students (15 males and 19 females).

STEM-PjBL Learning Procedure

Learning in the experimental class was implemented using the STEM-PjBL approach, which integrates science, technology, engineering, and mathematics through a water filtration project using banana peel activated carbon. The learning stages referred to the STEM-PjBL model developed by Laboy-Rush, namely reflection, research, discovery, application, and communication, as shown in Table 2.

Table 2. STEM-PjBL Learning Procedure Through Banana Peel Activated Carbon (Laboy-Rush, 2011)

STEM-PjBL Stage	Learning Activity	STEM Integration
Reflection	Students identified clean water problems and biomass waste utilization issues.	Science: water pollution and environmental problems
Research	Students investigated activated carbon properties and filtration principles.	Science + Technology: adsorption and activated carbon preparation
Discovery	Students designed filtration prototypes using banana peel activated carbon.	Engineering: design process and solution development
Application	Students constructed, tested, and evaluated filtration systems based on data.	Engineering + Mathematics: measurement and data analysis
Communication	Students presented results and reflected on the effectiveness of solutions.	Science communication and evaluation

The research instrument was an environmental literacy test consisting of 20 multiple-choice items developed based on the environmental literacy framework of McBeth and Volk (McBeth & Volk, 2010). The instrument covered four main dimensions: environmental knowledge, cognitive skills, environmental affect, and environmentally responsible behavior. Each dimension was represented by five items designed within the context of clean water quality and the use of biomass-based activated carbon. Before use, the instrument was validated by subject-matter experts and educational evaluation experts. The instrument was then tested on students outside the research sample to obtain information about item validity, reliability, difficulty level, and discrimination index (Arikunto, 2018). The results of the instrument analysis are presented in Table 3.

Table 3. Results of the Environmental Literacy Instrument Analysis

Analysis Aspect	Result
Number of Items	20
Validity	All items were valid
Reliability	alpha = 0.82 (High)
Difficulty Level	Moderate
Discrimination Index	Fair-Good

Data Analysis

The research data, consisting of pretest and posttest environmental literacy scores, were analyzed using descriptive and inferential statistics. Descriptive statistics were used to obtain the mean, standard deviation, minimum score, and maximum score. The normality test was conducted using Shapiro-Wilk, whereas the homogeneity of variance was tested using Levene's Test (Field, 2018).

Differences in initial ability between the experimental and control classes were analyzed using an independent sample t-test on pretest scores. The effectiveness of STEM-PjBL was analyzed using an independent sample t-test on posttest scores. The magnitude of improvement in environmental literacy was calculated using normalized gain (N-gain) (Hake, 1998). Furthermore, the magnitude of the treatment effect was analyzed using Cohen's d effect size (Cohen, 1988). The interpretation criteria for N-gain and effect size used in this study are presented in Table 4.

Table 4. Interpretation Criteria for N-Gain and Effect Size

Analysis	Value Range	Category
N-Gain	$g \geq 0.70$	High
	$0.30 \leq g < 0.70$	Moderate
	$g < 0.30$	Low
Partial Eta Squared (η^2)	≥ 0.14	Large effect
	0.06–0.14	Medium effect
	≤ 0.06	Small effect
Cohen's d	≥ 0.80	Very large effect
	0.50–0.79	Large effect
	0.20–0.49	Moderate effect
	< 0.20	Small effect

In addition to total score analysis, analysis was also conducted for each dimension of environmental literacy, including environmental knowledge, cognitive skills, environmental affect, and environmentally responsible behavior, to obtain a more comprehensive profile of environmental literacy improvement after the implementation of STEM-PjBL.

Results and Discussion

Before the implementation of STEM-PjBL, students' initial environmental literacy was measured through a pretest administered to both the experimental and control classes. This initial measurement aimed to ensure that both groups had relatively equivalent conditions before the treatment was given, so that differences appearing at the end of learning could be associated with the implemented intervention. In quasi-experimental research, equivalence of initial ability is an important aspect affecting internal validity because it enables researchers to compare the effects of treatment more objectively (Creswell & Creswell, 2018).

Table 5. Descriptive Statistics of Students' Initial Environmental Literacy

Group	Mean	SD	Minimum	Maximum
Experimental	48.94	9.98	30.00	65.00
Control	48.38	9.11	30.00	60.00

Based on Table 5, the mean pretest score of environmental literacy in the experimental class was 48.94 with a standard deviation of 9.98, whereas the control class obtained a mean score of 48.38 with a standard deviation of 9.11. The mean scores of the two groups showed only a very small difference; therefore, descriptively, the students' initial ability in both classes was relatively equivalent. These results indicate that before learning was implemented, students in both groups had nearly similar levels of understanding related to environmental knowledge, cognitive skills, environmental attitudes, and environmentally responsible behavior.

To statistically test the equivalence of initial ability, an independent sample t-test was conducted on students' environmental literacy pretest scores. The results are presented in Table 6.

Table 6. Results of the Independent Sample t-test for Pretest Scores

Variable	t	Sig. (2-tailed)
Environmental literacy	0.239	0.812

The analysis showed that, based on the significance value, there was no significant difference between the initial environmental literacy abilities of students in the experimental and control classes. Thus, both groups could be considered to have equivalent initial conditions before receiving different learning treatments. This

equivalence is important because it allows changes occurring after learning to be associated with the learning model implemented rather than with differences in initial ability between groups.

This finding also indicates that students' environmental literacy before learning remained in a relatively moderate category. This condition aligns with various international studies reporting that students' environmental literacy remains a challenge in science education and sustainability education. McBeth and Volk (2010) explained that many students possess basic understanding of environmental issues but are not yet able to integrate this knowledge into decision making and environmentally responsible actions. Similar results were reported by Oetari et al. (2024), who showed that mastery of environmental literacy has a positive relationship with problem-solving skills in environmental pollution, although the relationship remains relatively weak.

In addition, low initial environmental literacy may also be caused by limited learning experiences that connect science concepts with environmental problems occurring around students. UNESCO (2023) emphasized that the development of environmental literacy requires contextual, participatory, and problem-solving-oriented learning experiences so that students are able to develop knowledge, skills, attitudes, and behaviors that support sustainable development. Therefore, the equivalence of initial ability found in this study provides a strong basis for evaluating the effectiveness of the implementation of STEM-PjBL based on clean water availability issues in the subsequent learning stage.

Effect of STEM-PjBL on Environmental Literacy Based on ANCOVA

Considering the non-equivalent control group design employed in this study, an Analysis of Covariance (ANCOVA) was performed to provide a more robust estimation of the treatment effect. The pretest environmental literacy scores were included as a covariate, and the posttest environmental literacy scores were used as the dependent variable. The ANCOVA analysis was conducted to determine whether STEM-PjBL significantly influenced students' environmental literacy after adjusting for their initial environmental literacy levels.

Table 7. ANCOVA Assumption Tests

Assumption Test	Statistic	Sig.	Interpretation
Levene Test	1.744	0.191	Homogeneous variance
Pretest × Group	0.671	0.416	Homogeneous regression slope

The assumption tests indicated that the data met the requirements for conducting ANCOVA. The Levene's Test showed a significance value of 0.191 (>0.05), indicating that the variances between groups were homogeneous. Furthermore, the interaction effect between pretest scores and treatment groups was not statistically significant ($p = 0.416$), suggesting that the assumption of homogeneity of regression slopes was satisfied. Therefore, the ANCOVA analysis was considered appropriate for examining the effect of STEM-PjBL on students' environmental literacy after controlling for their initial abilities.

Table 8. Analysis of Covariance (ANCOVA) results

Source	Type III SS	df	Mean Square	F	Sig.	Partial Eta Squared
Pretest	2050.236	1	2050.236	59.795	<0.001	0.483
Treatment	4609.129	1	4609.129	134.425	<0.001	0.677
Error	2194.416	64	34.288			

The ANCOVA results demonstrated that the STEM-PjBL treatment was significantly associated with differences in students' environmental literacy after controlling for their initial abilities. The analysis revealed a significant effect of treatment, $F(1,64) = 134.425$, $p < 0.001$, partial $\eta^2 = 0.677$. The partial eta squared value indicates a very large effect size, suggesting that the STEM-PjBL implementation was associated with substantial differences in environmental literacy achievement between the experimental and control groups after controlling for initial abilities. The partial eta squared value was interpreted as the effect size of the

ANCOVA model, whereas Cohen's d was used to describe the practical magnitude of differences between groups. These findings indicate that the higher environmental literacy scores obtained by students in the experimental group were not merely attributed to differences in their initial abilities, but were associated with the learning experiences provided through the STEM-PjBL approach. The integration of clean-water availability issues and banana peel activated carbon filtration projects created a contextual learning environment where students could connect scientific concepts with real environmental problems.

The effectiveness of STEM-PjBL can be explained through its characteristics that integrate scientific inquiry, engineering design processes, problem-solving activities, and communication of solutions. Throughout the learning process, students were engaged in identifying water quality problems, investigating concepts related to environmental pollution and filtration mechanisms, designing filtration media using banana peel activated carbon, testing the developed solutions, and evaluating the effectiveness of their designs. These activities provided opportunities for students to apply scientific knowledge in addressing authentic environmental challenges.

This finding is consistent with the principles of integrated STEM education, which emphasizes the connection between science concepts and engineering practices to encourage students to develop solutions for real-world problems. Furthermore, project-based learning enables students to construct knowledge through active investigation, collaboration, and creation of meaningful products, thereby supporting deeper conceptual understanding and environmental awareness (Kokotsaki et al., 2016).

Improvement of Environmental Literacy Based on N-Gain

While ANCOVA was used as the main analysis to determine the treatment effect after controlling for pretest scores, N-gain analysis was performed as a complementary analysis to describe the extent of students' improvement in environmental literacy from pretest to posttest. The analysis was conducted by comparing pretest and posttest scores in the experimental and control classes, followed by calculating normalized gain (N-gain) to determine the level of environmental literacy improvement during the learning process.

Table 9. Comparison of Students' Environmental Literacy Scores

Group	Mean Pretest	Mean Posttest	N-Gain	Category
Experimental	48.94	85.45	0.727	High
Control	48.38	68.53	0.392	Moderate

Based on Table 9, the mean environmental literacy score in the experimental class increased from 48.94 at pretest to 85.45 at posttest. This improvement produced an N-gain score of 0.727, categorized as high. Meanwhile, the control class increased from 48.38 to 68.53, with an N-gain score of 0.392, categorized as moderate. These results indicate that the improvement in environmental literacy in the experimental class was higher than that in the control class. Thus, STEM-PjBL based on clean water availability issues demonstrated a greater improvement in students' environmental literacy compared with conventional learning. In addition to statistical significance, this study also analyzed the magnitude of the treatment effect using Cohen's d effect size. Furthermore, Cohen's d effect size analysis was conducted to examine the practical magnitude of the difference between the experimental and control groups. The results of the effect size analysis are presented in Table 10.

Table 10. Effect Size of STEM-PjBL Learning on Environmental Literacy

Cohen's d	Interpretation
2.09	Large

The effect size value indicates that the implementation of STEM-PjBL had a large effect on improving students' environmental literacy. This result shows that the observed difference was not only represented a substantial difference between groups but also indicated meaningful practical implications for science learning. The higher improvement in environmental literacy in the experimental class can be explained by the characteristics of STEM-PjBL, which positions students at the center of the learning process. Such active

involvement enables students to construct a deeper understanding of environmental issues while developing their ability to make environmentally responsible decisions (Baran et al., 2021; Ortiz-Revilla et al., 2022).

In this study, the context of clean water quality was an important factor supporting learning success. Water quality problems occurring in students' surrounding environment provided authentic learning experiences, enabling students to connect science concepts with real conditions they encounter in daily life. According to Portillo-Blanco et al. (2025), STEM learning integrated with real-world problems can increase the relevance of learning and encourage students to apply their knowledge in meaningful contexts. In addition, the filtration project using banana peel activated carbon provided students with direct experience in solving environmental problems through a scientific approach. During learning activities, students did not only learn concepts of pollution and water quality, but also observed water conditions, measured water quality parameters, designed filtration devices, and evaluated the effectiveness of the developed solution. This finding supports previous research showing that project-based learning has the potential to improve environmental literacy because it provides contextual, collaborative, and problem-solving-oriented learning experiences (Han et al., 2016; Kokotsaki et al., 2016).

The findings of this study also indicate that the development of environmental literacy requires learning experiences that actively involve students in observing, analyzing, and solving environmental problems. Learning that connects students directly with environmental issues encourages the formation of knowledge, cognitive skills, attitudes, and behaviors that support decision making regarding environmental problems (Napitupulu et al., 2025).

Overall, the results show that STEM-PjBL based on clean water availability issues is an effective approach for improving students' environmental literacy. The high N-gain value, the significant difference between the experimental and control groups, and the large effect size indicate that learning that integrates environment-based projects with the STEM approach can provide more meaningful learning experiences than conventional learning.

Profile of Environmental Literacy Improvement Based on Dimensions

The four dimensions of environmental literacy complement one another in forming an individual's ability to understand environmental problems, make evidence-based decisions, and act responsibly toward environmental sustainability (Ardoin et al., 2020; McBeth & Volk, 2010). Therefore, analyzing the improvement profile of each dimension is important for obtaining a more comprehensive picture of the contribution of STEM-PjBL based on clean water availability issues to the development of students' environmental literacy.

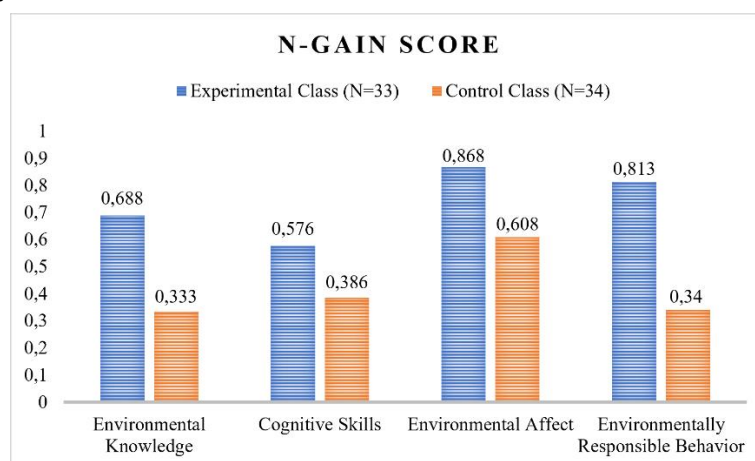


Figure 1. N-Gain Profile of Students' Environmental Literacy by Dimension

Based on Figure 1, all dimensions of environmental literacy in the experimental class showed greater improvement than those in the control class. In general, improvement in the experimental class ranged from moderate to high categories, whereas the control class tended to remain in the moderate category. This finding indicates that STEM-PjBL can support the development of environmental literacy more comprehensively than

conventional learning. Integrating environment-based projects with problems close to students' lives enables the learning process to become contextual and meaningful, so students not only acquire knowledge but also understand the relevance of the concepts learned to everyday life (Ortiz-Revilla et al., 2022; Portillo-Blanco et al., 2025).

The most prominent improvement was observed in the dimensions of environmental affect and environmentally responsible behavior. This condition indicates that learning originating from real environmental issues can build students' emotional connection with the problems studied while encouraging awareness to act. Such authentic learning experiences enable students to develop deeper concern, empathy, and responsibility toward the environment. Students' direct involvement in local environmental issues is known to contribute positively to the development of environmental awareness and the formation of sustainability values (Ardoin et al., 2020; Kalsoom et al., 2017).

Improvement in the dimension of environmentally responsible behavior indicates that students not only understand the importance of maintaining environmental quality but also begin to develop a tendency to implement actions that support environmental sustainability. Through the activities of making and testing filtration media, students gained real experience in utilizing biomass waste as a simple solution to water quality problems. Education for sustainable development emphasizes that the success of environmental learning is demonstrated not only by increased knowledge but also by students' ability to apply environmental values in responsible behavior (UNESCO, 2023).

In the environmental knowledge dimension, the improvement obtained indicates that STEM-PjBL helped students build a better understanding of water quality, environmental pollution, the sustainability of water resources, and the use of biomass as an environmentally friendly material. STEM learning integrated with authentic contexts is known to strengthen conceptual understanding problem because students are actively involved in problem-solving processes and the application of scientific concepts in real situations (Han et al., 2016; Ortiz-Revilla et al., 2022).

Meanwhile, improvement in the cognitive skills dimension indicates that learning provided students with opportunities to develop the ability to identify problems, analyze information, interpret data, and design solutions to environmental problems. Analytical, evaluative, and -solving abilities are complex skills that develop gradually through sustained learning experiences.

Overall, the improvement profile for each dimension indicates that the implementation of STEM-PjBL based on clean water availability issues through a filtration project using banana peel activated carbon can develop environmental literacy holistically. Learning not only improved mastery of environmental concepts but also strengthened students' concern, responsibility, and ability to respond to environmental problems through real actions. This finding shows that the use of local environmental issues as a context for science learning has the potential to support the development of sustainability competencies, which are among the main goals of twenty-first-century education and Education for Sustainable Development (ESD) (OECD, 2023; UNESCO, 2023).

Contribution of STEM-PjBL Stages to the Development of Environmental Literacy

The improvement in students' environmental literacy cannot be separated from the characteristics of STEM-PjBL, which provides staged learning experiences through problem identification, investigation, solution design, implementation, and communication of results. In this study, the STEM-PjBL stages referred to a model consisting of reflection, research, discovery, application, and communication. Each stage provided complementary learning experiences that supported the development of different environmental literacy dimensions; therefore, the learning process was oriented not only toward concept mastery but also toward the integrated development of environmental skills, attitudes, and behaviors. The relationship between STEM-PjBL stages and environmental literacy dimensions is presented in Table 11.

Table 11. Contribution of STEM-PjBL Stages to Environmental Literacy

STEM-PjBL Stage	Learning Activity	Environmental Literacy Dimension Supported
Reflection	Observing water conditions and identifying problems	Environmental affect
Research	Collecting information about water quality and activated carbon	Environmental knowledge
Discovery	Designing filtration media	Cognitive skills
Application	Creating and testing filtration device	Cognitive skills and environmentally responsible behavior
Communication	Presenting results and reflection	All dimensions

Based on Table 11, each STEM-PjBL stage provided complementary learning experiences that supported the development of students' environmental literacy. During the learning process, students not only gained an understanding of water quality and environmental pollution, but were also directly involved in investigation and problem-solving activities through a filtration project using banana peel activated carbon. Students' involvement in designing filtration media and testing water quality provided opportunities to integrate scientific concepts with real practices relevant to the surrounding environmental conditions. The implementation of STEM-PjBL projects during the study is presented in Figure 2.

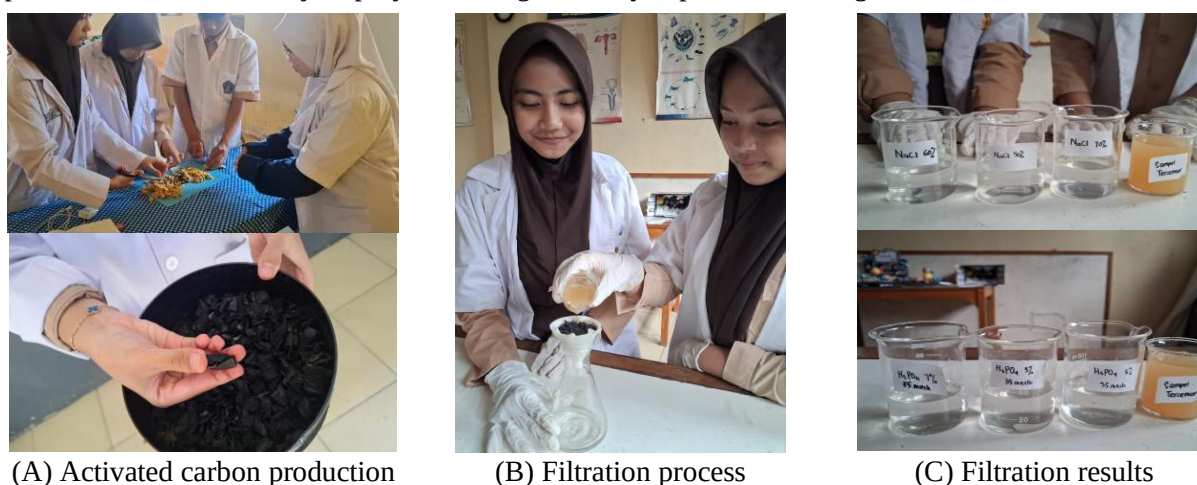


Figure 2. Implementation in STEM-PjBL learning: (A) Production of activated carbon from banana peels; (B) Simple filtration process for polluted water; (C) Filtration results

The activities shown in Figure 2 indicate that students were actively involved in the discovery and application stages as part of the project-based learning process. Direct involvement in designing and testing solutions enabled students to build a deeper understanding of the relationship between scientific concepts and environmental problems occurring around them. Learning that provides opportunities for students to develop solutions to real problems is known to increase learning engagement and strengthen sustainability competencies needed in the twenty-first century (Brundiers et al., 2021; Wiek et al., 2011).

At the reflection stage, when students were confronted with problems close to their daily lives, the learning process became more meaningful because they could understand the relevance of the material studied to real conditions faced by society. Learning approaches that raise local environmental issues are known to increase students' emotional engagement and concern for the environment, thereby supporting the development of the environmental affect dimension. The research stage contributed to the development of environmental knowledge through activities involving information collection and analysis of various concepts related to water quality, environmental pollution, adsorption, and the use of biomass as an activated carbon material.

A strong contribution to the development of cognitive skills was observed in the discovery and application stages. These activities encouraged students to conduct analysis, evaluation, and decision making

based on the observations obtained. STEM learning that integrates the engineering design process is known to develop critical thinking and problem-solving skills because students are required to produce solutions based on available evidence (Baran et al., 2021; English, 2021). In addition to developing cognitive skills, the application stage also contributed to the development of environmentally responsible behavior. Direct experience in utilizing biomass waste as a filtration medium provided students with opportunities to apply their knowledge in concrete actions that benefit the environment.

Learning experiences involving real action through project-based learning have been shown to improve pro-environmental behavior because students are actively involved in developing and implementing solutions to environmental problems (Azrai et al., 2024; Hastuti et al., 2024). The communication stage functioned as a reflective stage that strengthened all dimensions of environmental literacy through presentations and discussions of project results. Students communicated their findings, evaluated the effectiveness of the solutions developed, and reflected on the implications of project results for efforts to maintain environmental quality.

Overall, the results indicate that STEM-PjBL based on clean water availability issues was an effective learning approach for supporting students' environmental literacy development within the context of this study. The integration of environmental problem observation, scientific investigation, solution design, project implementation, and communication of results enabled students to obtain authentic and meaningful learning experiences. This finding reinforces that STEM-PjBL based on clean water availability issues is not only effective in improving environmental literacy but also capable of bridging the relationship between scientific knowledge and concrete action in efforts to support environmental sustainability.

Conclusion

This study found that STEM-PjBL based on clean water quality issues through a filtration project using banana peel activated carbon was associated with significantly higher environmental literacy outcomes among Grade IX students. The experimental and control groups showed comparable baseline environmental literacy, while the experimental group demonstrated greater improvement after the intervention. The improvement was observed in the overall environmental literacy score and descriptively across the four dimensions: environmental knowledge, cognitive skills, environmental affect, and environmentally responsible behavior. Students' involvement in identifying water quality problems, investigating activated carbon, designing filtration media, collecting and analyzing data, and evaluating the developed solution provided contextual learning experiences that connected scientific concepts with real environmental problems. The findings indicate that integrating authentic local environmental issues into STEM-PjBL can support the development of students' environmental literacy through the integration of scientific investigation, engineering design, data analysis, and environmental problem solving. This approach is also aligned with the principles of Education for Sustainable Development (ESD) and provides a contextual alternative for environmental science learning at the junior high school level.

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