



STEM Biofertilizer Project for Students' Scientific Literacy and Environmental Awareness in Elementary Schools

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Abstract

This study aims to investigate the effectiveness of STEM project-based learning in developing elementary students' scientific literacy and environmental awareness through the creation of eco-friendly biofertilizer. The study employed a mixed-methods approach with a single group pretest-posttest design, involving 24 fourth-grade students from an elementary school in Sidoarjo, Indonesia. Quantitative data was collected through scientific literacy tests and environmental awareness questionnaires, and then analyzed using descriptive statistics and difference tests (Wilcoxon test and paired-samples t-test). Meanwhile, qualitative data was gathered through student response questionnaires and structured interviews, and analyzed using thematic analysis. The results revealed a significant improvement in both scientific literacy (Wilcoxon test: $Z = -4.031$, $p < 0.05$) and environmental awareness (paired t-test: $t = -9.093$, $p < 0.05$). The interviews and responses indicated that most students became more aware of their environment, especially in caring for plants and in understanding the differences between natural and chemical fertilizers. These findings suggest that STEM project-based learning can provide meaningful learning experiences while also positively simultaneously affecting students' scientific literacy and environmental awareness.

Keywords:

Scientific literacy; environmental awareness; STEM project-based learning; biofertilizer

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INTRODUCTION

Recent discussions have focused heavily on global environmental issues, especially land degradation, pollution, and climate change. These issues, if left unaddressed, could threaten human sustainability (Ali & Rahman, 2024; Ballard & Mooring, 2021). Sustainable Development Goal (SDG) 15: Life on Land emphasizes conserving biodiversity, preventing land degradation, and sustainable resource use (Liu et al., 2019; Nandi et al., 2025). In Indonesia, the excessive use of chemical fertilizers degrades soil quality and fertility and pollutes the environment (Marliati et al., 2025; Murnita & Taher, 2021). These issues are increasingly significant concerns across different areas of life, including education.

Education plays an important role in fostering environmental awareness and responsibility early on, helping students understand concepts and take real action to address environmental issues. Elementary school is especially significant because in this stage, students' character, habits, and attitudes towards the environment are established (Kopbossyn et al., 2025; OECD, 2018; Otto & Pensini, 2017). This calls for early

educational innovation to prepare future generations with scientific literacy and sufficient environmental awareness, enabling them to tackle sustainability issues, particularly in science education.

Science education at the elementary level still faces various challenges. The current teaching practices tend to be overly theoretical and focused on rote memorization, rather than promoting critical thinking skills, problem-solving abilities, and students' environmental awareness among students. Recent studies have revealed that this lack of contextualized learning leads to a low ability among students to apply scientific concepts to real-world problems, thereby limiting scientific literacy and environmental awareness (Karnoto et al., 2025; Dewi et al., 2024; Pertiwi et al., 2024). As a result, students often have difficulty relating scientific concepts to real phenomena in their daily lives, including understanding environmental issues around them.

In science education, scientific literacy is the ability to understand natural phenomena and make evidence-based decisions. According to the OECD framework for PISA, it includes mastering scientific concepts and using scientific knowledge to evaluate evidence and make decisions about scientific issues in daily life. Key competencies are explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically (OECD, 2019). Beyond cognitive skills, environmental learning aims to foster positive attitudes toward the environment. Environmental awareness involves environmental literacy, emphasizing cognitive, affective, and dispositional aspects. It covers general beliefs/values, personal attitudes, and knowledge/knowledge about environmental issues, highlighting attitudes, values, and the goal of sustainable behavior (Kaya & Elster, 2019; Yildirim et al., 2025).

The rise of science and technology in the 21st century calls for innovation in elementary education to develop learners' critical thinking, creativity, collaboration, and communication skills (Beers, 2014; Roberts & Bybee, 2014; Council et al., 2011; Rahayu, 2017). One important approach is Science, Technology, Engineering, and Mathematics (STEM) (English, 2016; Lu et al., 2022). STEM emphasizes understanding scientific concepts and real-world problem-solving skills, which are vital to preparing the next generation to address global issues (Grinfeldt et al., 2024; Margot & Kettler, 2019).

In this context, an instructional approach that integrates science with contextual experiences and real-world problem-solving becomes highly relevant. Some studies have shown that STEM project-based learning (STEM-PjBL) is effective in improving scientific literacy and student engagement (Afriana et al., 2016; Listiyana et al., 2023; Pratama et al., 2025). Other research also indicates that this approach can support the development of students' environmental awareness (Pertiwi et al., 2024). However, most studies still focus on projects based on general themes and have not yet integrated real ecological practices, especially at the elementary level. Additionally, research that simultaneously examines scientific literacy and environmental awareness within a single learning intervention remains limited.

An innovative method to address the previous gaps involves STEM project-based learning that uses experiments to create eco-friendly biofertilizers. Biofertilizers are made from organic materials such as leaves, kitchen waste, and other local resources. This project encourages students to learn about the scientific processes and simple technologies involved in processing organic materials and to apply engineering principles to create useful products. Moreover, it provides practical experience showing how straightforward innovations can contribute to environmental sustainability and support the Sustainable

Development Goals, especially SDG 15, which concerns the protection of terrestrial ecosystems.

This study examines the effect of STEM project-based learning on elementary students' scientific literacy and environmental awareness through the creation of eco-friendly biofertilizers. It bridges theory and practice, developing 21st-century skills. The science part covers decomposition processes; technology involves simple tools; engineering focuses on designing procedures; and mathematics includes measurement and data analysis (Dewi et al., 2021). The STEM project model promotes active student participation from planning to implementation and reflection, fostering not only cognitive development but also a sense of environmental responsibility (Abdurrahman et al., 2023; Maspul, 2024). Experiments such as producing biofertilizers showed that simple solutions can support ecosystem health, aligning with SDG 15: Life on Land.

SDG 15 emphasizes the need for educational innovations from an early age, given the serious impacts of soil degradation and excessive use of chemical fertilizers on ecosystems. International research highlights the importance of environmental education in elementary education (Lu et al., 2022). Nonetheless, there are few studies on implementing STEM through eco-friendly experiments, such as biofertilizer production, despite their relevance to daily life, especially in farming communities.

This study's novelty lies in integrating biofertilizer production into a STEM project-based learning model. This approach affects scientific literacy and fosters environmental awareness through hands-on activities. It offers empirical evidence on the effectiveness of STEM project learning focused on sustainability, serving as a replicable model to advance SDG 15 at local and national levels.

Based on these observations, several key questions guide this research: 1) How is the implementation of STEM project learning to integrate the production of eco-friendly biofertilizer in elementary schools?; 2) How does integrating the practice of making eco-friendly biofertilizer in STEM projects influence students' scientific literacy?; 3) How does integrating the practice of making eco-friendly biofertilizer in STEM projects influence students' environmental awareness?

METHODS

This study employs a mixed-methods approach with an embedded design, in which quantitative data serve as the primary source and are supported by qualitative data (Creswell & Creswell, 2018). This method was selected to provide a thorough understanding of how STEM project learning, specifically through the practice of creating eco-friendly biofertilizer, affects elementary students' scientific literacy and environmental awareness.

The research starts with a quantitative phase, employing a pre-experimental study with a one-group pretest-posttest design. This design was selected because the school has only one established class, making it impractical to create a control group without interrupting the learning process or raising ethical issues. Quantitative data are collected through a scientific literacy test and an environmental awareness questionnaire, and then analyzed statistically to evaluate treatment effects. Subsequently, qualitative data are gathered through a student response questionnaire and structured interviews to complement the quantitative findings, which are then identified using thematic analysis. The final step involves combining both data types to develop a complete understanding of the effect of STEM project learning, integrating biofertilizer production.

The participants were 24 fourth-grade students at Muhammadiyah 5 Elementary School in Porong, Sidoarjo Regency, East Java. Fourth-grade students typically possess

basic scientific literacy skills and environmental awareness and are ready to participate in simple experimental activities. The school was selected because it has been implementing the Pancasila Student Profile Strengthening Project (P5) with an environmental theme since 2022. Its location in a semi-urban area facilitates the implementation of project-based STEM learning focused on environmental sustainability.

Before conducting empirical tests of construct validity and reliability, the instruments underwent expert validation. The purpose was to ensure that the items align with scientific literacy and environmental awareness indicators, are appropriate in content, clearly constructed, and use proper language suitable for elementary school students. Expert validation confirms that the instrument meets content validity standards. Feedback from experts is used to revise the instrument, ensuring its appropriateness for empirical testing.

Data collection used both quantitative and qualitative methods to understand students' science literacy and environmental awareness. The scientific literacy test was given before (pretest) and after (posttest) the intervention. It consists of 15 multiple-choice questions divided among three competencies: (1) explaining phenomena scientifically, (2) evaluating and designing scientific inquiry, and (3) interpreting data and evidence scientifically (OECD, 2019). Students also completed a 24-item environmental awareness questionnaire that used a four-point Likert scale (Sugiyono, 2018). It covers three main concepts: (1) general beliefs or values, (2) attitudes, and (3) knowledge/information (Kaya & Elster, 2019; Yildirim et al., 2025). Validity and reliability checks were completed for each item before testing.

The validity of the scientific literacy test was assessed using Corrected Item–Total Correlation in SPSS, with items having correlations ≥ 0.30 , indicating adequate correlation (Pallant, 2020). Reliability was assessed using Cronbach's Alpha, with values ≥ 0.70 considered acceptable (Fraenkel et al., 2023). The test was piloted with 23 respondents, who were different from the main participants. All items showed correlation coefficients above 0.30 and Cronbach's Alpha value above 0.70, confirming their validity and reliability for this study. The analysis results are presented in Table 1.

Table 1. Validity & Reliability Test of Scientific Literacy Instrument

Dimension	No. Item	Corrected Item- Total Correlation	I	Cronbach's Alpha	I
Explaining phenomena scientifically	1, 2, 3, 4, 5	0.366 – 0.813	Valid	0.880	High Reliability
Evaluating and designing scientific inquiry	6, 7, 8, 9, 10	0.353 – 0.706	Valid		
Interpreting data and evidence scientifically	11, 12, 13, 14, 15	0.463 – 0.732	Valid		

I = Interpretation

Results show that all 15 items differentiated students of varying abilities, with no negative correlations or low scores, so all items were retained. Cronbach's Alpha was 0.880, indicating high internal consistency. This confirms the scientific literacy instrument's reliability and suitability for research.

The environmental awareness questionnaire was administered to 22 respondents, who are different from the main participants, as a pilot test. The validity test confirms that all items meet the criteria. Moreover, its reliability was assessed with Cronbach's Alpha. Both results are in Table 2.

Table 2. Validity and Reliability Test of Environmental Awareness Instrument

Dimension	No. Item	Corrected Item- Total Correlation	I	Cronbach's Alpha	I
General Belief/Values (Affective Dimension)	1, 2, 3, 4, 5, 6, 7, 8	0.330 – 0.777	Valid	0.879	High Reliability
Personal Attitudes (Dispositional Dimension)	11, 12, 13, 14, 15, 16	0.300 – 0.578	Valid		
Information/Knowledge (Cognitive Dimension)	17, 18, 19, 20, 21, 22, 23, 24	0.323 – 0.690	Valid		

I = Interpretation

Based on Table 2, all 24 questionnaire items had a Corrected Item–Total Correlation of ≥ 0.30 , indicating they were valid for measuring environmental awareness. Correlation values ranged from 0.300 to 0.777, showing moderate to strong relationships with the total score. The reliability test yielded a Cronbach's alpha of 0.879, indicating high internal consistency. This confirms the questionnaire reliably measures environmental awareness, making it suitable for this study.

Qualitative data were collected through a student response questionnaire and structured interviews with 24 students after implementation. The questionnaire includes six items that focus on how each STEM aspect is implemented through the project. Following this, structured interviews with the same questions were conducted to dig deeper into the topics, ensuring consistency and facilitating easier comparison. Structured interviews involve a prepared set of questions, limiting additional inquiries to stay focused (Cresswell & Cresswell, 2018).

Data analysis was conducted in an integrated manner. Quantitative data were examined using descriptive statistics and tests of differences between pretest and posttest scores. Before hypothesis testing, the data were checked for normality using the Shapiro–Wilk test. If the data were normally distributed, a paired-sample t-test could be performed. Otherwise, the nonparametric Wilcoxon Signed-Rank Test was used.

The magnitude of the intervention's effect was measured using the effect size. For data analyzed with the Wilcoxon test, the effect size was determined using the r statistic, calculated as $r = \frac{Z}{\sqrt{N}}$, where 0.1 indicates a 'small' effect, 0.3 indicates a 'medium' effect, and 0.5 or higher indicates a 'large' effect (Cohen, 1988). Meanwhile, for data analyzed with a paired-sample t-test, the effect size was expressed as Cohen's d for paired samples, calculated as $d_z = \frac{t}{\sqrt{n}}$, where 0.2 indicates a 'small' effect, 0.5 indicates a 'medium' effect, and 0.8 or higher indicates a 'large' effect (Cohen, 1988).

The qualitative data were analyzed in stages: data reduction, presentation, and conclusion. Overall, qualitative findings supported the interpretation of quantitative results.

RESULTS & DISCUSSION

Result

This study was conducted at SD Muhammadiyah 5 Porong from January 22 to 29, 2026. Twenty-four fourth-graders were involved in the research. Observations showed that the implementation of STEM projects on environmental conservation went well. Learning followed the STEM Project-Based Learning stages: reflection, research, discovery, application, and communication. The approach included making liquid organic fertilizer from katuk leaves and emphasized scientific concepts, simple technology, engineering, and math. Initially, students identified materials and prepared katuk leaves for fertilizer. The

STEM integration became evident in the science, technology, engineering, and mathematics areas (See Figures below).



Figure 1. Collecting Organic Material (Katuk Leave)



Figure 2. Students Blend Katuk Leaves



Figure 3. Students Determine the Appropriate Biofertilizer Dilution Ratio



Figure 4. Students Measure Katuk Leaves

Figure 1 shows an activity focused on the scientific aspect, in which students study how to use natural materials as organic fertilizer (katuk leaves). They learned about organic matter decomposition, microorganisms, macronutrients (N, P, K), nutrient cycles, and their effects on soil fertility and sustainability. Activities involved collecting and identifying materials like leaves, peels, and scraps, observing fermentation changes such as color, odor, gas, and alterations, and testing fertilizer effects on plants.

Figure 2 illustrates the use of technology, including tools such as a blender for pureeing leaves, a digital scale, and microorganisms (MOL) for fermentation. Students also use a mixer and strainer to ensure proper mixing. These tools help students understand how technology converts organic waste into eco-friendly products.

Figure 3 covers the engineering aspect, where students experiment with mixing ratios of biofertilizer to water, testing ratios 1:5, 1:10, and 1:15 by volume. They use 50 mL of biofertilizer with varying amounts of water to determine the optimal concentration. Results showed the 1:10 ratio (50 mL fertilizer + 500 mL water) produced the best plant response. Excessively concentrated solutions like 1:5 increase osmotic pressure around roots, restricting water uptake, while too dilute solutions like 1:15 provide fewer nutrients. The 1:10 ratio balances nutrient levels for optimal absorption. Students applied this solution to plants on campus, learning about experimental design and biofertilizer as an alternative to chemicals.

Figure 4 depicts mathematical concepts in measuring and proportioning ingredients, such as using cups and scales for accurate mixing. Overall, the project demonstrates how four STEM elements integrate into environmental education, helping students understand science and develop skills in technology, engineering, and measurement.

This study assesses students' scientific literacy after a STEM project implementing the creation of eco-friendly biofertilizer, comparing pretest and posttest scores of 24 students scaled to 0–100. Data analysis included descriptive stats, normality, Wilcoxon Signed-Rank Test, and effect size r . The initial analysis was performed to provide an overview of students' scientific literacy skills before and after the implementation of the learning program. The descriptive statistics for the pretest and posttest scores are shown in Table 3.

Table 3. Descriptive Statistics of Scientific literacy Scores

Test	N	Minimum	Maximum	Mean	Std. Deviation
Pretest	24	33	93	77.83	15.050
Posttest	24	47	100	88.88	11.837

According to Table 3, students' average pretest score was 77.83 ($SD = 15.050$), and the average posttest score increased to 88.88 ($SD = 11.837$). The lowest score rose from 33 on the pretest to 47 on the posttest, and the highest score increased from 93 to 100. These results show an effect in students' scientific literacy skills after the STEM project-based learning.

In assessing distribution, the data were analyzed using the Shapiro–Wilk test. The normality test results showed that the p -values for the pretest and posttest were 0.001 and 0.000 (< 0.05). This indicates that the data are not normally distributed. Therefore, the analysis was continued using the Wilcoxon Signed-Rank Test as a nonparametric alternative. The analysis results are shown in Table 4.

Table 4. Results of the Wilcoxon Signed-Rank Test

Variable	Negative Ranks (N)	Positive Ranks (N)	Ties (N)	Z	Sig. (p)
Posttest – Pretest	0	21	3	-4.031	0.000

According to Table 4, all 21 students' scores increased, although 3 students had the same scores on the pretest and posttest. The results of the Wilcoxon test showed a Z -value of -4.031 with a p -value of $p = 0.000$ ($p < 0.05$), indicating a significant difference between the pretest and posttest scores. Therefore, STEM project-based learning that incorporates the creation of eco-friendly biofertilizers significantly affects students' scientific literacy.

In addition to analyzing score differences, this study also evaluated the effect on students' scientific literacy by measuring the effect size. The results is in Table 5 below.

Table 5. Effect Size (r) of Scientific Literacy Test

Variable	Z Value	N	Effect Size (r)	Interpretation
Scientific Literacy (Pre–Post)	-4.031	24	0.82	Large Effect

The analysis reveals an effect size (r) of 0.82, classified as a 'large' effect. This means the difference between pretest and posttest scores is both statistically significant. In essence, the intervention had a notable effect on students' scientific literacy.

This study also examined changes in students' environmental awareness after participating in the STEM project learning. The data were gathered using a 24-item questionnaire administered to 24 students before and after the learning activity. The results of the descriptive statistical analysis are shown in Table 6.

Table 6. Descriptive Statistics of Environmental Awareness Scores

Test	N	Minimum	Maximum	Mean	Std. Deviation
Pretest	24	54	82	70.71	6.517
Posttest	24	75	95	83.58	5.266

According to Table 6, the mean score for students' environmental awareness before the treatment was 70.71 (SD = 6.517), while after the treatment it increased to 83.58 (SD = 5.266). The minimum score also rose from 54 on the pretest to 75 on the posttest, and the maximum score increased from 82 to 95. These results indicate an effect on students' environmental awareness levels following their participation in the learning process.

Before the t-test, the data were tested for normality using the Shapiro–Wilk test, yielding p-values of 0.639 for the pretest and 0.548 for the posttest (> 0.05), indicating a normal distribution. This allowed the use of a paired-sample t-test to assess differences in environmental awareness scores. Results are shown in Table 7 below.

Table 7. Results of the Paired-Sample t-test

Variable	Mean Difference	t	df	Sig. (2-tailed)
Pretest – Posttest	-12.875	-9.093	23	0.000

The analysis results show a notable difference in environmental awareness scores before and after the lesson. The mean difference between the pretest and posttest scores is -12.875, with a t-value (df=23) of -9.093 and a p-value of 0.000 ($p < 0.05$). These findings suggest that the STEM project affects students' environmental awareness.

To determine the magnitude of the effect, an effect size analysis was also used for the environmental awareness test. The analysis results are shown in Table 8 below.

Table 8. Effect Size (Cohen's d) of Environmental Awareness

Variable	t Value	N	Effect Size (r)	Interpretation
Environmental Awareness (Pre–Post)	-9.093	24	1.86	Large Effect

The analysis shows that the effect size (Cohen's d) is 1.86, which falls into the large effect category. This indicates that the difference between pretest and posttest scores is substantial. In other words, the intervention was associated with a strong effect on students' environmental awareness.

Qualitative data in this study were obtained through student response questionnaires consisting of six questions, filled out by 24 students after the intervention. To deepen the responses given in the questionnaires, structured interviews with the same questions were conducted with all participants. The use of interconnected instruments aims to better understand students' perceptions of their learning experiences. Questionnaires and interviews explore perceptions of learning, environmental awareness, biofertilizer concepts, and scientific skills developed during STEM projects. These qualitative data complement and enhance the interpretation of quantitative results.

Qualitative data analysis involved data reduction, presentation, and drawing conclusions. Key themes included positive learning responses, increased environmental awareness, a better understanding of fertilizer concepts and impacts, and the development of scientific skills. Most students related their learning to daily life, especially in understanding simple technology, making biofertilizer, and applying science in environmental conservation.

Based on the survey results, 87.5% of students agreed or strongly agreed that the learning activities affected their environmental awareness. This finding is supported by interview results, which show that students link learning to real actions like caring for plants and preserving environmental balance.

One student stated, "*Saya belajar menjaga tanaman karena tanaman penting bagi manusia.*" (I am learning to take care of plants because plants are important to humans) [Student A]. Another student also explained, "*Jika tanaman tidak dirawat maka lingkungan menjadi tidak sehat dan banyak polusi.*" (If plants are not cared for, the environment becomes unhealthy and there's a lot of pollution) [Student N].

These statements indicate students are starting to understand the connection between plant conservation and environmental quality. Project-based learning provides hands-on experiences that highlight the importance of caring for our environment. Moreover, 79.2% of them reported that they can understand and address simple environmental issues. Interview data support this finding, with students identifying issues such as wilting or yellowing plants and providing practical solutions, such as watering or fertilizing.

One student explained, "*Jika ada tanaman layu atau daunnya menguning, saya buru-buru menyiramnya.*" (If a plant is wilting or its leaves are turning yellow, I quickly water it) [Student K]. Another student said, "*Tanaman yang hampir mati bisa dirawat dengan memberi pupuk dan air.*" (Plants that are nearly dead can be cared for by giving them fertilizer and water) [Student A].

These responses show that students can link scientific ideas to real-world situations in their environment. They not only identify problems but also suggest simple solutions that they can implement.

The technological aspect of STEM learning was shown in students' ability to use tools and materials to produce biofertilizer. 79.2% of students agreed or strongly agreed they could use these tools during activities. Interview data further clarified this, with some students mentioning the use of basic measuring instruments like measuring cups or graduated cylinders.

One student stated, "*Mengukur air menggunakan gelas takaran.*" (Measuring water using a measuring cup) [Student F]. Another student explained, "*Menuangkan air dengan takaran 250 ml menggunakan gelas ukur.*" (Pouring 250 ml of water using a measuring cup) [Student G].

These responses show that students are starting to understand how to use simple technology in experimental activities. Using measuring tools helps students see that technology can support practical problem-solving.

The engineering aspect was evident in students' participation in creating biofertilizer to improve plant growth. 79.2% of them agreed or strongly agreed with statements regarding their experience in making organic fertilizer. Interviews revealed that students not only understood the concepts but also engaged actively in the production process.

One student explained, "*Saya pernah membuat pupuk dari daun katuk lalu diberikan ke tanaman agar subur.*" (I once made fertilizer from katuk leaves and applied it to the plants to make them grow well) [Student R]. Another student also stated, "*Pengalaman membuat pupuk organik cair dari daun katuk di kelas.*" (The experience of making biofertilizer from katuk leaves in class) [Student A].

These statements suggest that students participated in designing and creating a basic product to address environmental concerns. This activity provided students with practical experience in applying simple engineering principles.

The mathematical concepts in the activity primarily appeared when students measured material weights and water volumes in the process of making biofertilizer. 62.5% of students agreed or strongly agreed that math concepts were used in the learning activities. This was further supported by interview data.

One student explained, "*Menimbang berat memakai timbangan.*" (Weighing the materials using a scale) [Student H]. Another student stated, "*Mengukur volume air menggunakan gelas ukur.*" (Measuring the volume of water using a measuring cup) [Student K].

These responses show that students used basic math skills in practical activities. Even though the math concepts were simple, this activity helped students see why precise measurements matter in experiments.

Students demonstrated scientific literacy by explaining environmental issues, observing plants, and understanding the environmental impacts of fertilizer use. 62.5% of them agreed or strongly agreed with statements concerning scientific literacy skills. Additionally, interview findings indicate that the STEM project-based learning provides a positive educational experience for students.

One student stated, "*Saya mengamati tanaman dan melihat apakah tanaman itu sehat atau tidak.*" (I observed the plants and checked whether they were healthy or not) [Student A]. Another student explained, "*Pupuk kimia bisa merusak tanah, sedangkan pupuk alami lebih ramah lingkungan.*" (Chemical fertilizers can damage the soil, while natural fertilizers are more environmentally friendly) [Student G]

These statements show that students can observe phenomena around them, understand what causes problems, and communicate their understanding in simple terms. This demonstrates the growth of basic scientific literacy among students through project-based learning. Overall, the questionnaire data, supported by interview results, indicate that STEM project learning incorporating the creation of biofertilizer provides a positive effect and a meaningful learning experience for students, both in terms of environmental awareness and the development of scientific literacy.

Discussion

Results indicate that incorporating biofertilizer creation into STEM project learning has positive effects on elementary students' scientific literacy. Project-based STEM education offers contextual and authentic experiences, enabling students to understand concepts theoretically and apply them in practice (Bybee, 2013; Han et al., 2015). Creating biofertilizer allows students to observe scientific processes firsthand, such as organic material decomposition, thus enhancing their skills in explaining phenomena, designing simple investigations, and interpreting data. These results support research showing that STEM project-based methods can boost science literacy by merging concepts with practices and fostering active student participation in learning (Parno et al., 2020; Pratama et al., 2025; Syukri et al., 2025; Utami et al., 2025).

In addition to improving scientific literacy, the research shows a significant increase in students' environmental awareness. Environmental awareness includes values, attitudes, and knowledge as key parts of environmental literacy, involving understanding of the environment through cognition, values, and attitudes. Creating organic fertilizer from natural materials like katuk leaves gave students hands-on experience reusing waste to benefit the environment. Through this activity, students not only get knowledge about environmental issues but also develop caring attitudes toward their environment. This process demonstrates that experiential learning can strengthen the affective and behavioral dimensions of environmental awareness (Widyastuti et al., 2020). Therefore, direct involvement in environment-based activities can enhance students' attitudes and sustainable behaviors.

Results from the student response questionnaire indicate that most students felt more aware of their environment after participating in the project. This aligns with interview findings, which indicated that students gained a better understanding of plant care and viewed biofertilizers as more eco-friendly than chemical fertilizers. Additionally, students mentioned using simple measuring tools, making organic fertilizers from natural materials, and monitoring plant health, illustrating how project-based activities help them grasp scientific concepts concretely. These experiences demonstrate the integration of science, technology, engineering, and mathematics in addressing environmental issues. STEM project learning is known to improve students' understanding and problem-solving

abilities through real-world contexts and to boost engagement by linking learning to everyday life (Roberts & Bybee, 2014).

This study confirms that STEM project learning incorporating the creation of biofertilizers is not only effective in influencing science literacy but also in shaping elementary school students' environmental awareness. It indicates that integrating scientific concepts with practical sustainability into learning has great potential to produce meaningful, relevant, and sustainable education.

The results of this study have important implications for teaching practices in elementary schools. Teachers can utilize STEM project approaches by integrating local environmental issues as relevant and meaningful learning contexts. Activities such as making bio-fertilizer can serve as alternative teaching strategies to increase student engagement while also fostering environmental awareness. Additionally, learning that combines experimental activities, problem-solving, and reflection can help students develop scientific literacy more deeply.

Future research should adopt more rigorous experimental designs, like quasi-experimental or true experimental setups with control groups, to strengthen the validity of the findings. Furthermore, conducting studies with larger and more diverse samples will help enhance the generalizability of the results. Future research might also focus on incorporating digital technology into STEM project learning and expanding research on science literacy and environmental topics across various scientific disciplines.

CONCLUSION

This study demonstrates that STEM project learning that incorporated the creation of biofertilizers was associated with significant effects in students' scientific literacy and environmental awareness. The findings are demonstrated through pretest–posttest differences and effect sizes. Regarding scientific literacy, the results indicate a Z-value of -4.031 with a p-value of $p = 0.000$ ($p < 0.05$), signifying that the intervention significantly affects students' scientific literacy. Additionally, the effect size of 0.82 indicates a large effect of the intervention. Regarding environmental awareness, a t-value of -9.093 with $df = 23$ and a p-value of $p = 0.000$ ($p < 0.05$) also indicates a significant effect of the intervention. The substantial effect size of 1.86 further implies a strong effect on students' environmental awareness. These results are corroborated by questionnaire and interview data, which demonstrate increased environmental awareness, an enhanced understanding of plant care and eco-friendly biofertilizers, and an improved capacity to apply scientific concepts in real-world situations. These findings highlight that integrating scientific concepts with practical sustainability through hands-on activities, such as producing biofertilizers, can create meaningful and engaging learning experiences while promoting problem-solving skills and connections across science, technology, engineering, and mathematics.

Teachers are encouraged to implement STEM project approaches by incorporating relevant environmental issues to enhance both students' scientific literacy and environmental awareness. However, given the use of a one-group pretest–posttest design, the results should be interpreted with caution. Future research is recommended to employ more rigorous experimental designs with control groups and larger, more diverse samples to strengthen the validity and generalizability of the findings and to expand the research across various scientific disciplines.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

- Abdurrahman, A., Maulina, H., Nurulsari, N., Sukamto, I., Umam, A. N., & Mulyana, K. M. (2023). Impacts of integrating engineering design process into STEM makerspace on renewable energy unit to foster students' system thinking skills. *Heliyon*, 9(4), e15100. <https://doi.org/10.1016/j.heliyon.2023.e15100>
- Afiana, J., Permanasari, A., & Fitriani, A. (2016). Project based learning integrated to STEM to enhance elementary school's students scientific literacy. *Jurnal Pendidikan IPA Indonesia*, 5(2), 261–267. <https://doi.org/10.15294/jpii.v5i2.5493>
- Ali, I., & Rahman, A. (2024). Environmental degradation: Causes, effects and solutions. *International Journal For Multidisciplinary Research*, 6(3), 1–10. <https://doi.org/10.36948/ijfmr.2024.v06i03.20366>
- Ballard, J., & Mooring, S. R. (2021). Cleaning our world through green chemistry: Introducing high school students to the principles of green chemistry using a Case-Based Learning module. *Journal of Chemical Education*, 98(4), 1290–1295. <https://doi.org/10.1021/acs.jchemed.9b00312>
- Beers, S. Z. (2014). 21st century skills: preparing students for their future. *Gigiena i Sanitariia*, 93(6), 13–17. https://www.yinghuaacademy.org/wp-content/uploads/2014/10/21st_century_skills.pdf
- Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA Press.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2nd ed.)*. Lawrence Erlbaum Associates.
- Council, N. R. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. National Academies Press.
- Creswell, J.W. and Creswell, J.D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage, Los Angeles.
- Dewi, C. C. A., Erna, M., Haris, I., & Kundera, I. N. (2021). The effect of contextual collaborative learning based ethnoscience to increase student's scientific literacy ability. *Journal of Turkish Science Education*, 18(3), 525–541. <https://doi.org/10.36681/tused.2021.88>
- Dewi, N. K. S., Parmiti, D. P., & Werang, B. R. (2024). Scientific literacy aspects of environmental awareness of fifth-grade students influenced by the creative problem-solving (CPS) learning model. *Jurnal Ilmiah Pendidikan dan Pembelajaran*, 8(2), 367–378. <https://doi.org/10.23887/jipp.v8i2.71504>
- English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, 3(1), 3. <https://doi.org/10.1186/s40594-016-0036-1>
- Grinfeldt, Y., Kurbanov, A., & Vershinina, I. (2024). Sustainable Development Goals in Brazil in the context of the global environmental Agenda 21 (using the example of SDG 15). *E3S Web of Conferences*, 555, 4002. <https://doi.org/https://doi.org/10.1051/e3sconf/202455504002>
- Han, S., Capraro, R., & Capraro, M. M. (2015). How Science, Technology, Engineering, and Mathematics (STEM) Project-Based Learning (PBL) affects high, middle, and low achievers differently: The impact of student factors on achievement. *International Journal of Science and Mathematics Education*, 13(5), 1089–1113. <https://doi.org/10.1007/s10763-014-9526-0>
- Karnoto, B. K., Dwiyanto, D., & Arsyad, M. (2025). The Impact of Project-Based Learning on Students' Scientific literacy and Environmental Awareness: A Comprehensive Review. *Journal of Pedagogi*, 2(5), 95–106. <https://doi.org/10.62872/80h4ry59>
- Kaya, V. H., & Elster, D. (2019). A critical consideration of environmental literacy: Concepts, contexts, and competencies. *Sustainability (Switzerland)*, 11(6).

- <https://doi.org/10.3390/su11061581>
- Kopbosyn, A., Laiskhanov, S., Aksoy, B., Tokbergenova, A., Nametkulov, M., & Kozybakova, A. (2025). Integrated STEM for sustainability in school and early teacher education: a systematic review (2019–2025). *Frontiers in Education*, 10(October). <https://doi.org/10.3389/educ.2025.1697058>
- Listiyana, A., Bima, M. Z. A., Khusna, N., Dewi, P. W. C., Putri, S. R., Yuniarti, Y., Anantanukulwong, R., Angoy, R. D., & Sukardi, R. R. (2023). Implementation of STEM-oriented learning strategy toward science literacy skills in elementary school students. *Journal of Environment and Sustainability Education*, 1(1), 20–26. <https://doi.org/10.62672/joease.v1i1.6>
- Liu, S., Bai, J., & Chen, J. (2019). Measuring SDG 15 at the county scale: Localization and practice of SDGs indicators based on geospatial information. *ISPRS International Journal of Geo-Information*, 8(11), 515. <https://doi.org/doi:10.3390/ijgi8110515>
- Lu, S. Y., Lo, C. C., & Syu, J. Y. (2022). Project-based learning oriented STEAM: the case of micro-bit paper-cutting lamp. *International Journal of Technology and Design Education*, 32(5), 2553–2575. <https://doi.org/10.1007/s10798-021-09714-1>
- Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: a systematic literature review. 2. <https://doi.org/https://doi.org/10.1186/s40594-018-0151-2>
- Marliati, Vaulina, S., Dewi, I. S., & Dewi, D. C. (2025). The model of organic fertilizer adoption in urban farming to support environmentally friendly agriculture in Pekanbaru City, Riau Province, Indonesia. *Asian Journal of Agriculture and Rural Development*, 15(2), 223–235. <https://doi.org/10.55493/5005.v15i2.5410>
- Maspul, K. A. (2024). Exploring STEM education for real-world climate change concerns to empower students as change agents. *Journal of Physics Education and Science*, 1(2), 12. <https://doi.org/10.47134/physics.v1i2.249>
- Murnita, & Taher, Y. A. (2021). Dampak pupuk organik dan anorganik terhadap perubahan sifat kimia tanah dan produksi tanaman padi (*Oriza sativa L.*). *Jurnal Menara Ilmu*, XV(2), 67–76. <https://doi.org/https://doi.org/10.31869/mi.v15i2.2314>
- Nandi, S., Das, S., Gorain, S., Dutta, S., Roy Choudhury, M., & Das, S. (2025). Land degradation neutrality: A pathway to achieving sustainable development goals and ecosystem resilience. *Discover Soil*, 2, 48. <https://doi.org/10.1007/s44378-025-00078-9>
- OECD. (2018). *The OECD PISA global competence framework: preparing our youth for an inclusive and sustainable world*. OECD, 43. <https://www.oecd.org/education/Global-competency-for-an-inclusive-world.pdf>
- OECD. (2019). PISA 2018 assessment and analytical framework. In *OECD Publishing*. <https://doi.org/10.1787/b25efab8-en>
- Otto, S., & Pensini, P. (2017). Nature-based environmental education of children: Environmental knowledge and connectedness to nature, together, are related to ecological behaviour. *Global Environmental Change*, 47(August), 88–94. <https://doi.org/10.1016/j.gloenvcha.2017.09.009>
- Pallant, J. (2020). *SPSS Survival Manual A step by step guide to data analysis using IBM SPSS*. Routledge. <https://doi.org/https://doi.org/10.4324/9781003117452>
- Parno, Yuliati, L., Ndadari, I. P., & Ali, M. (2020). Project based learning integrated stem to increase students' scientific literacy of fluid statics topic. *Journal of Physics: Conference Series*, 1491(1). <https://doi.org/10.1088/1742-6596/1491/1/012030>
- Pertiwi, T. U., Oetomo, D., & Sugiharto, B. (2024). The effectiveness of STEM Project-Based Learning in improving students' environmental literacy abilities. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 10(2), 476–485.

- <https://doi.org/10.22219/jpbi.v10i2.33562>
- Pratama, H., Matsun, Puspitasari, Y. D., & Maduretno, T. W. (2025). Science literacy through STEM-based project based learning model. *Jurnal Penelitian Pendidikan IPA*, 11(7), 320–330. <https://doi.org/10.29303/jppipa.v11i7.11306>
- Rahayu, S. (2017). Promoting the 21st century scientific literacy skills through innovative chemistry instruction. *AIP Conference Proceedings*, 1911. <https://doi.org/10.1063/1.5016018>
- Roberts, D. A., & Bybee, R. W. (2014). Scientific literacy, scientific literacy, and science education. In *Handbook of research on science education, Volume II* (pp. 559–572). Routledge.
- Sugiyono. (2018). *Metode penelitian kuantitatif, kualitatif, dan R&D*. Bandung: CV. Alfabeta.
- Syukri, M., Maghfirah, S., & Herliana, F. (2025). Engineering design process in PjBL-STEM teaching materials to improve students' scientific literacy skills. *Journal of Physics: Conference Series*, 3139(1), 1–11. <https://doi.org/10.1088/1742-6596/3139/1/012086>
- Utami, V. B., Wilujeng, I., & Rahmawati, L. (2025). Effectiveness of STEM-based project instructional materials on newton's laws in improving scientific literacy. *Journal of Physics: Conference Series*, 3139(1). <https://doi.org/10.1088/1742-6596/3139/1/012101>
- Widyastuti, F., Probosari, R. M., Sajidan, Saputro, S., & Sutikno. (2020). Developing environmental awareness through experiential learning: A critical analysis of higher education students' practices. *Journal of Physics: Conference Series*, 1511(1). <https://doi.org/10.1088/1742-6596/1511/1/012098>
- Yildirim, M. S., Elkoca, A., Gökçay, G., Yilmaz, D. A., & Yıldız, M. (2025). The relationship between environmental literacy, ecological footprint awareness, and environmental behavior in adults. *BMC Public Health*, 25(1). <https://doi.org/10.1186/s12889-025-21340-3>