

Enhancing Critical Thinking Skills and Science Literacy Through Stem-Based Problem Learning in Elementary School: Contributions To SDG 4 AND SDG 13

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Abstract. This study was driven by the observed deficiencies in elementary students' critical thinking skills and science literacy, which are essential foundations for advancing Sustainable Development Goal (SDG) 4 on quality education and SDG 13 on climate action. The novelty of this research resides in the contextual integration of STEM-based problem learning focused on climate change issue at the elementary school level, complemented by an integrated evaluation of 21st-century skills development and its alignment with the global Sustainable Development Goals (SDGs). Unlike previous STEM-PBL studies that primarily emphasize cognitive gains or general STEM competencies, this study uniquely embeds climate change as an authentic problem context and systematically links learning outcomes to the SDG framework, providing a clearer pedagogical contribution and comparative advantage. The method used in this study was a quasi-experiment with a non-equivalent control group design. The sample consisted of 62 fourth-grade elementary school students divided into two groups, an experimental group that received STEM-based problem learning and a control group that received conventional instruction. The research instruments comprised a critical thinking skills tests and a science literacy questionnaire, which had been validated by experts. The data were analyzed using inferential statistical tests, and including t-tests. The results indicated that the experimental group exposed to STEM-based problem learning experienced a statistically significant increase in critical thinking skills and science literacy compared to the control group. Students were actively engaged in all stages of the problem, ranging from design and implementation to the presentation of innovative solutions. The findings confirm that STEM-based problem learning is not only effective in enhancing students' cognitive and science literacy competencies but also plays a strategic role in fostering awareness of global issues, particularly climate change. Therefore, this model is proposed as an innovative pedagogical approach to advance the attainment of SDG 4 and SDG 13 within the context of elementary education. These contributions collectively position the study as a more contextually grounded and SDG-responsive extension of prior STEM-PBL research.

Keywords: Problem-Based Learning, STEM, Critical Thinking, Science Literacy, SDGs.

INTRODUCTION

Science education plays a crucial role in developing the foundations of scientific thinking, critical thinking skills, and awareness of global issues related to environmental sustainability, such as climate change. In the 21st-century context, the educational paradigm has transformed from merely mastering factual knowledge to developing Higher Order Thinking Skills (HOTS), including critical thinking skills and scientific literacy (Afandi et al., 2018). In contemporary education, critical thinking skills are one of the primary goals to be achieved at every level of learning (Atiaturrahmaniah et al., 2022). Meanwhile, scientific literacy is defined as the ability to use scientific knowledge to explain phenomena, evaluate evidence-based information, and make decisions in a socio-environmental context (Elhai,

2023). Therefore, critical thinking skills and scientific literacy are crucial to develop from elementary school onwards so that students can think scientifically, be responsible, and actively participate in public issues relevant to environmental sustainability.

International assessment results show that Indonesian students' science performance remains far below the average for OECD (Organization for Economic Co-operation and Development) countries. This is evident from the average score of Indonesian students in the Programme for International Student Assessment (PISA) science, which was recorded at 383 points, down from 396 points in 2018 and significantly below the OECD average of 485 points (OECD, 2023). These data indicate that the majority of students in Indonesia have not yet mastered the basic scientific skills that are prerequisites for understanding and applying scientific concepts in real life. The downward trend in scores from 2018 to 2022 also shows that science learning in schools has not been able to optimally foster scientific thinking and evidence-based reasoning skills. Thus, science learning in Indonesia is often still dominated by memorization and lectures, which tends to hinder the development of students' critical thinking skills. As a result, students are less able to relate science concepts to real life and are not trained to solve problems independently.

A learning process that fosters these two abilities ideally provides space for exploration and meaningful learning experiences. According to (Purnamasari & Utomo, 2020), the application of STEM-based problem learning can enhance human capacity resources that meet 21st century needs, such as critical thinking, problem-solving, collaboration, creativity, and environmental awareness. This approach enables cross-disciplinary integration and fosters comprehensive conceptual understanding. STEM education with a problem-based learning approach focuses on solving meaningful problems for students. Learning is directed towards real-world contexts so that students not only understand concepts theoretically but also are able to relate them to practical situations (Smith et al., 2022) Through this process, students develop the ability to utilize their skills and knowledge in authentic, life-oriented problem-solving practices. Empirical studies confirm its effectiveness, STEM-PBL has been shown to improve critical thinking (Lestari et al., 2024).

Previous research has shown that the Problem-Based Learning (PBL) approach integrated with STEM is effective in improving critical thinking skills and scientific literacy. Purnamasari & Utomo (2020) found that STEM-PBL can significantly improve students' analytical and problem-solving skills. Meanwhile, the results of research conducted by Bahriah & Irwandi (2020) showed that the implementation of problem-based learning integrated with

STEM can improve students' scientific literacy, particularly in the aspect of scientific understanding. This proves that the integration between Problem-Based Learning and the STEM approach can strengthen the learning process by emphasizing improving scientific literacy while developing students' critical thinking skills.

However, (Sabina et al., 2025) emphasized that the implementation of SDGs-based STEM learning in schools is still rare and has not been systematically integrated. Teachers and students still have limited understanding of the relationship between STEM and sustainable development, which causes learning to not be oriented towards developing scientific and environmental awareness. Therefore, this study aims to fill this gap by developing a STEM-based Problem Learning learning model that not only integrates science, technology, engineering, and mathematics, but also fosters critical thinking skills and scientific literacy through the context of problems relevant to real life and global environmental issues.

Although many studies have explored STEM-PBL, few have explicitly integrated it with real-life environmental issues on SDGs, especially at the elementary school level. Existing research often focuses only on improving cognitive outcomes without embedding broader socio-environmental dimensions such as climate action, sustainability, or responsible decision-making. Thus, this study is designed to fill that gap by developing a STEM-based Problem Learning model that systematically integrates SDG-related environmental contexts to enhance critical thinking skills and scientific literacy among elementary school students. This model aligns with SDG 4 (Quality Education), which encourages the development of 21st century skills, and SDG 13 (Climate Action), which promotes awareness and action on climate change through education.

METHODOLOGY

Research Design

This study employed a quantitative method with experimental research as the type of research. This research approach employed a quasi-experimental approach. The quasi-experimental approach was chosen because the researchers in this study did not have the flexibility to manipulate the sample, so the control class and the experimental class were selected based on random class selection from a population (Abraham & Supriyati, 2022). This study employed a pretest-posttest control group design. In this design, there were two classes designated as the control group and the experimental group. The control group was

taught using conventional methods, while the experimental group was taught using STEM-based project learning. The research design used in this study is shown in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Control	O ₁	-	O ₃
Experiment	O ₂	X	O ₄

Description:

O₁: Control group pretest

O₂: Experimental group pretest

-: No treatment

X: Treatment given

O₃: Control group posttest

O₄: Experimental group posttest

Population and Samples

This research design aimed to determine the effectiveness of two learning methods used in two different groups. This research was conducted at a public school in Bekasi Regency, West Java. This study was conducted in fourth-grade elementary school with a sample of 62 students, who were divided into two groups. The control group contained 31 students and the experimental group contained 31 students. The sampling technique used purposive sampling. This method selects samples based on specific criteria determined by the researcher (Jaya, 2020).

Research Procedures

The research was conducted through a pretest given to two groups. Next, the experimental group received a STEM-based problem learning treatment, while the control group received no treatment. The final step was a posttest given to both groups to determine the effectiveness of the learning model applied to both groups. Data obtained from the pretest and posttest results were then analyzed using normality tests, homogeneity tests, and t-tests to determine the effectiveness of the learning model after the treatment.

Research Instrument

The instrument used in this study was a critical-thinking test developed based on Facione (2011) six aspects of critical thinking. The six aspects shown in Figure 1.



Figure 1. Facione's Six Aspects of Critical Thinking

These six aspects served as the conceptual framework for constructing indicators that reflect the cognitive processes expected from students when solving science problems related to climate action. Each aspect was operationalized into measurable indicators that were adapted to the developmental level of fourth-grade students. These indicators guided the preparation of the test items, ensuring that each item aligned with both the targeted critical-thinking skill and the science content being assessed. The items were designed to require students to interpret environmental information, analyze causes and effects, evaluate possible solutions, draw logical conclusions, explain scientific reasoning, and reflect on their environmental decisions. A visual depiction of Facione's six aspects was included to illustrate the theoretical foundation used in developing the instrument. This ensures that the construction of the test items is transparent, conceptually grounded, and consistent with established critical-thinking theory.

RESULTS AND DISCUSSION

Descriptive Data Analysis

The results of the data obtained through the pretest and posttest were then analyzed using SPSS software version 31. The data obtained from the pretest and posttest of both groups were subsequently analyzed using descriptive statistical techniques. This analysis is presented in the form of boxplot diagrams to provide a visual overview of the distribution of scores, measures of central tendency, and variations among respondents in each group. The visualization aims to illustrate differences in score patterns between the experimental and control groups before and after the intervention was implemented. The boxplot diagram shown in Figure 2.

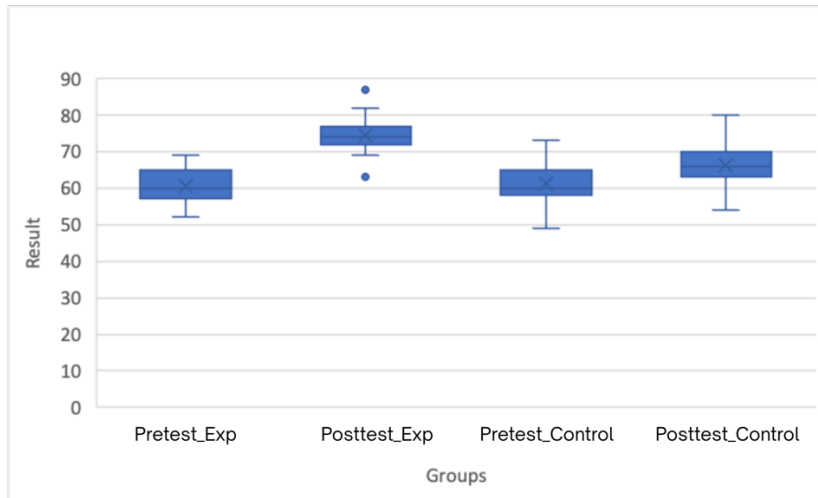


Figure 2. Boxplot Diagram

Based on the boxplot diagrams, the pretest scores of both groups show a relatively similar distribution, with the median positioned around a value of 60. However, following the intervention, the experimental group demonstrates a clear improvement, indicated by an increase in the posttest median to approximately 74. In addition, the interquartile range in the posttest of the experimental group shows a more concentrated and stable distribution, suggesting that the improvement occurred relatively evenly among the students.

In the control group, the posttest median increased to around 66, although the improvement was not as substantial as that observed in the experimental group. The score distribution in the control group also appears wider, indicating greater variability in student performance in the absence of a specific instructional intervention. The presence of outliers in the posttest of the experimental group further indicates that some students achieved scores considerably higher than the general trend.

Overall, the visual patterns presented in the boxplot diagrams indicate that the experimental group experienced a more significant improvement in learning outcomes than the control group. This improvement is reflected through the higher median values, the shift of score distribution toward a higher range, and the consistency of student achievement following the implementation of the learning intervention. The data obtained from the pretest and posttest results were then tested for normality of the data obtained, which is shown in Table 2.

Tests of Normality

Table 2. Tests of Normality

Result	Group	Shapiro-Wilk		
		Statistic	df	Sig.
	Pre_Ex	.961	31	.314
	Post_Ex	.976	31	.696
	Pre-Control	.987	31	.962
	Post_Control	.981	31	.829

Based on the Shapiro–Wilk normality test results table, the significance values (Sig.) for each group were as follows: Experimental Pretest (Pre-Ex) = 0.314; Experimental Posttest (Post-Ex) = 0.696; Control Pretest (Pre-Control) = 0.962; Control Posttest (Post-Control) = 0.829. The decision-making criteria for the normality test are: If the Sig. value is > 0.05, the data are normally distributed; if the Sig. value is < 0.05, the data are not normally distributed. From these results, all significance values are greater than 0.05, thus concluding that the data in all groups are normally distributed.

The results of the normality test indicate that the data from the experimental and control groups, both before and after treatment, are normally distributed. This means that the scores obtained by the participants in this study are proportionally distributed around the mean value and there are no extreme deviations.

A normal data distribution indicates that the initial conditions of both groups were relatively balanced and that the treatment did not cause extreme differences in participant learning outcomes. Therefore, parametric statistical tests (such as the t-test) can be used to more accurately analyze differences in outcomes between the two groups. Overall, these results strengthen the validity of the research data because they demonstrate that the data meet the basic assumption of statistical analysis, namely normal distribution. The next step is a homogeneity test to determine the distribution of the data, as shown in Table 3.

Test of Homogeneity

Table 3. Test of Homogeneity of Variance

		Levene		
		Statistic	df2	Sig.
Result	Based on Mean	1.285	60	.262
	Based on Median	1.288	60	.261
	Based on Median and with adjusted df	1.288	59.666	.261
	Based on trimmed mean	1.279	60	.263

Based on the Test of Homogeneity of Variance table using Levene's test, a significance value (Sig.) was obtained. The decision-making criteria are: If the Sig. value is > 0.05 , then the variance between groups is homogeneous, and if the Sig. value is < 0.05 , then the variance between groups is not homogeneous. From these results, all significance values are greater than 0.05. Thus, it can be concluded that the data from the experimental and control groups have homogeneous variance.

The results of the homogeneity test indicate that the data variation between the experimental and control groups is not significantly different. This means that the distribution of scores in both groups has a nearly equal level of diversity. This is important because it indicates that any differences in learning outcomes that may arise are not due to differences in data diversity, but rather to the treatment or learning method applied.

With the homogeneity assumption met, further analysis can use a parametric test (independent sample t-test) to examine the differences in the means of the two groups. This strengthens the validity of the data and demonstrates that the study was conducted under balanced conditions between the experimental and control groups. Overall, the results of this test indicate that both groups have a good level of variance equality, making the data suitable for further hypothesis testing. The results of the hypothesis testing are shown in Table 4.

Test of Independent sample t-test

Table 4. t-test

		Significance Two-Sided p	Mean Difference	Std. Error Difference
Result	Equal variances assumed	<.001	8.355	1.408
	Equal variances not assumed	<.001	8.355	1.408

Based on the Independent Sample t-Test results table, a significance value (Two-Sided p) of <0.001 was obtained for both the assumed and not assumed equal variances conditions. The decision-making criteria for the t-test include: If the Sig. (p) value is <0.05, there is a significant difference between the two groups; if the Sig. (p) value is >0.05, there is no significant difference.

A significance value less than 0.05 indicates a significant difference between the learning outcomes of the experimental and control groups. The Mean Difference value of 8.355 indicates that the average learning outcomes of the experimental group were 8.355 points higher than those of the control group, with a Standard Error Difference of 1.408.

The results of this t-test indicate that the treatment given to the experimental group had a significant impact on improving student learning outcomes. The very small significance value (<0.001) indicates that the difference between the experimental and control groups did not occur by chance, but was truly caused by the intervention or learning method applied to the experimental group.

This finding confirms the results of the previous descriptive analysis, where the experimental group experienced a greater increase in average scores than the control group. Therefore, it can be concluded that the learning method applied to the experimental group was more effective in improving learning outcomes than the method used in the control group.

A significance value significantly lower than 0.05 indicates a significant difference in learning outcomes between the experimental class using STEM-based Problem Learning and the control class using conventional methods. This finding demonstrates that the implementation

of STEM-based Problem Learning significantly improves student learning outcomes, which in the context of this study include critical thinking skills, scientific literacy, and problem-solving. The higher average learning outcome scores in the experimental class reflect the success of this approach in activating student participation and fostering deeper scientific reasoning.

Linkage to SDG 4 (Quality Education)

The implementation of STEM-based Problem Learning directly supports Sustainable Development Goal 4 (Quality Education), which emphasizes the importance of improving the quality, relevance, and equity of education at all levels. In this context, learning is not solely oriented towards academic outcomes but also directed towards developing students who think critically, are able to adapt to change, and play an active role in sustainable development. The problem-based learning model within the STEM framework focuses on developing 21st-century competencies, such as critical thinking, collaboration, communication, and creativity (the 4Cs), which are the main pillars of modern education.

This approach aligns with target 4.7 of SDG 4, which aims to ensure that all learners acquire the knowledge and skills necessary to support sustainable development, one of which is through education for environmental sustainability. By using problem learning, students are trained to deal with complex situations, identify real-world problems in their environment, and design innovative solutions based on scientific knowledge. This creates an inclusive and participatory learning environment, where students become active participants in the learning process, not simply recipients of information.

Beyond its impact on academic outcomes, implementing this approach also has important socio-pedagogical implications. By integrating collaboration and communication in small groups, students learn to respect differences of opinion and develop empathy and social skills. These values align with SDG 4's mission to promote equitable learning, respect diversity, and contribute to peaceful and sustainable societies.

Furthermore, STEM-based Problem Learning encourages students' emotional engagement and intrinsic motivation in the learning process. Because the problems raised are contextual and relevant to their lives, students feel a direct connection to the material being studied. This increased motivation creates a deeper learning experience than rote-based learning. Thus, this approach not only develops cognitively competent students but also fosters scientific attitudes such as curiosity, rigor, and responsibility for the learning process.

Linkage to SDG 13 (Climate Action)

In addition to improving learning outcomes and critical thinking skills, the implementation of STEM-based Problem Learning also contributes significantly to Sustainable Development Goal 13 (Climate Action), which focuses on increasing the capacity of individuals and communities to address climate change. This model not only teaches science as a collection of facts, but also utilizes it as a tool for thinking and acting to understand and find solutions to environmental problems.

Within the problem-based learning framework, students are trained to identify, analyze, and find scientific solutions to real-world environmental issues around them. Through the stages of STEM-based problem-solving (problem identification, concept exploration, solution design, and outcome evaluation), students use a scientific approach to address existing ecological challenges.

This aligns with the research findings of Purwaningsih et al. (2025) which showed that the implementation of SDG-based STEM learning significantly improved students' critical thinking skills and environmental awareness. Learning activities oriented towards solving ecological problems encourage the emergence of ecological awareness and environmental responsibility, two important indicators in developing environmentally friendly behavior from elementary school age.

Through problem-based learning experiences, students learn that climate change is not an isolated issue, but rather interconnected with social, economic, and technological dimensions. They understand that solutions to environmental challenges require systemic thinking and cross-disciplinary collaboration, which are at the heart of STEM education. Over the long term, these experiences foster climate literacy, the ability to understand the causes, impacts, and mitigation and adaptation efforts to climate change a competency that is foundational to sustainable development.

CONCLUSION

The results of the study showed that the implementation of STEM-based Problem Learning significantly improved student learning outcomes. The average score for the experimental group increased from 60.61 (pretest) to 74.52 (posttest), while the control group only increased from 61.16 to 66.16. The t-test yielded a significance value of <0.001 with a mean difference of 8.355, indicating a significant difference between the two groups. These findings

demonstrate that STEM-based Problem Learning effectively enhances students' conceptual understanding, problem-solving abilities, and engagement in science learning.

Overall, the implementation of STEM-based Problem Learning transforms science learning into more than just a means to understand the world, but also a means to preserve and improve it. This model helps realize the synergy between SDG 4 (Quality Education) and SDG 13 (Climate Action), creating a generation of young people who are critical, innovative, and concerned about the sustainability of the earth, an essential foundation for a sustainable future.

However, this study has several limitations. First, the sample size and research setting were limited to a single school, which may restrict the generalizability of the findings to broader populations. Second, the intervention duration was relatively short, making it difficult to measure the long-term sustainability of improvements in critical thinking skills and scientific literacy.

Future research should explore the implementation of STEM-based Problem Learning across diverse educational settings and grade levels to strengthen generalizability. Longitudinal studies are also recommended to assess the long-term effects on students' scientific literacy, environmental awareness, and climate-related decision-making. Additionally, future implementations could integrate digital tools, outdoor learning, or community-based environmental projects to further enhance students' engagement and real-world application of STEM concepts. From a practical standpoint, teacher training and the development of context-rich STEM learning resources are crucial to support wider adoption of this model in elementary schools.

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