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Enhancing Problem-Solving Skills in Science through STEM-Based Learning

A Case Study of Eighth-Grade Students at SMPN 1 Satap Wara, Indonesia

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ABSTRACT

Developing students' science problem-solving ability is a critical objective in contemporary STEM education. This study investigated the effect of STEM-based instruction integrated with Problem-Based Learning (PBL) on the science problem-solving abilities of eighth-grade students at SMPN 1 Satap Wara. A pre-experimental one-group pretest–posttest design was employed involving 22 students selected through total sampling. Data were collected using a validated science problem-solving test administered before and after the intervention. Descriptive statistics indicated a substantial increase in the mean score from 19.00 (SD = 8.429 in the pretest to 51.41 (SD = 8.534) in the posttest. Inferential analysis using a paired-samples t-test revealed a statistically significant improvement in students' problem-solving abilities ($p < 0.001$), with a large effect size (ES = 0.785), indicating strong practical significance. The integration of STEM and PBL facilitated active engagement in authentic problem contexts, promoting critical thinking, creativity, and collaborative learning processes. Despite the overall improvement, some students did not achieve the minimum competency standard, suggesting the need for differentiated instructional support. These findings provide empirical evidence supporting the effectiveness of STEM-based instruction in enhancing science problem-solving abilities and contribute to the growing body of literature on pedagogical strategies that prepare students with essential competencies for 21st-century learning.

Keywords
Critical Thinking
Middle School Students
Problem-Based Learning
Problem-Solving Skills
Science Education
STEM-Based Learning

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Introduction

Engaging and meaningful learning experiences are fundamental to fostering students' motivation, attention, and academic achievement in science education [1]. When students are actively involved in learning processes that connect scientific concepts with authentic contexts, they are more likely to develop deeper conceptual understanding and higher-order thinking skills. However, traditional teacher-centered instruction often emphasizes memorization and passive knowledge acquisition, resulting in reduced student engagement, limited conceptual understanding, and diminished problem-solving capacity [2]. This instructional limitation remains a persistent challenge, particularly in developing countries where science education frequently prioritizes content coverage over inquiry, application, and interdisciplinary integration.

One promising approach to addressing these challenges is STEM-based learning, which integrates science, technology, engineering, and mathematics into a cohesive instructional framework. When combined with Problem-Based Learning (PBL), STEM-based instruction promotes active learning through authentic problem-solving, enabling students to develop critical thinking, creativity, and collaborative competencies [3]–[4]. PBL encourages students to explore real-world problems, engage in inquiry-based investigation, and construct knowledge through experiential learning processes. For example, STEM-PBL activities involving renewable energy projects enable students to connect scientific principles with practical applications, thereby strengthening both conceptual understanding and scientific reasoning [5]. Empirical evidence suggests that active learning approaches are increasingly adopted in Indonesian STEM education, with 87.5% of studies employing Project-Based Learning, 8.3% utilizing Problem-Based Learning, and 4.16% implementing hybrid approaches, highlighting the growing recognition of student-centered pedagogies in STEM instruction [6].

The integration of STEM and PBL provides a comprehensive framework for developing essential 21st-century competencies, including problem-solving, technological literacy, innovation, and collaborative skills [7]–[8]. Through interdisciplinary learning and authentic problem engagement, students develop the ability to analyze complex situations, apply scientific reasoning, and propose evidence-based solutions. These competencies are critical for

preparing students to meet the demands of rapidly evolving technological and scientific landscapes.

Despite the growing body of literature supporting STEM and PBL approaches [9], several important gaps remain. First, many previous studies have focused primarily on general academic achievement, conceptual understanding, or student engagement, while empirical evidence specifically examining science problem-solving ability as a measurable outcome remains limited, particularly at the middle school level. Second, although STEM and PBL have been widely studied independently, fewer studies have examined their integrated implementation as a unified pedagogical framework. Third, within the Indonesian context, there is still insufficient empirical research investigating the effectiveness of STEM-PBL integration in rural or under-resourced schools, where instructional innovation is often constrained. Preliminary observations at SMPN 1 Satap Wara indicate that science instruction continues to rely on conventional methods, with limited integration of STEM principles and authentic problem-solving activities. This condition highlights the need for empirical investigation into instructional approaches that can enhance students' science problem-solving abilities.

The novelty of this study lies in its empirical examination of the integrated STEM and Problem-Based Learning approach specifically targeting science problem-solving abilities among middle school students in a rural Indonesian context. Unlike prior studies that focus primarily on conceptual learning outcomes or general academic performance, this study emphasizes problem-solving ability as a critical higher-order cognitive skill essential for 21st-century learning. Furthermore, this study provides context-specific evidence on the effectiveness of STEM-PBL integration in supporting active learning and developing students' scientific reasoning and practical problem-solving competencies.

Based on these considerations, the research question guiding this study is: To what extent does STEM-based Problem-Based Learning affect the science problem-solving abilities of eighth-grade students at SMPN 1 Satap Wara? This study aims to provide empirical evidence on the effectiveness of STEM-based PBL in improving students' problem-solving abilities and to contribute to the development of effective instructional strategies for enhancing science education in secondary schools.

Methods

A. Research Design

This study employed a quantitative pre-experimental approach using a one-group pretest–posttest design to examine the effect of STEM-based Problem-Based Learning (PBL) on students' science problem-solving abilities. This design enables the measurement of changes

in students' performance before and after the instructional intervention, thereby allowing the evaluation of the intervention's effectiveness. The research was conducted at SMPN 1 Satap Wara, located in Dusun Wara, Desa Korobhera, Kecamatan Mego, Kabupaten Sikka, during the first semester of the 2024/2025 academic year.

B. Participants

The participants consisted of 22 eighth-grade students selected through purposive sampling. This sampling technique was used to ensure that participants met specific criteria relevant to the study, including enrollment in the target science class and participation in the STEM-based instructional intervention. All participants had similar curricular exposure and had not previously experienced structured STEM-based PBL instruction, ensuring consistency in baseline learning conditions.

C. Research Instrument

Data were collected using pretest and posttest instruments designed to measure students' science problem-solving abilities. Each test consisted of five essay questions aligned with the national curriculum and STEM-based learning objectives. The essay format was selected to assess higher-order cognitive skills, including problem identification, analysis, reasoning, and solution development.

The instrument underwent expert validation to ensure content validity, construct relevance, and instructional alignment. Validation was conducted by subject matter experts and instructional media experts, who evaluated the instrument based on clarity, relevance, and appropriateness for measuring science problem-solving abilities. Revisions were made based on expert feedback to ensure the instrument's validity and reliability.

D. Instructional Procedure

The instructional intervention was implemented using an integrated STEM-based Problem-Based Learning framework over the designated instructional period. The learning process followed five key stages adapted from established PBL models integrated with STEM principles: (1) problem orientation, where students were introduced to real-world science problems; (2) student organization, where students formed small collaborative groups and defined investigation tasks; (3) guided investigation, where students conducted inquiry, collected data, and explored possible solutions; (4) product development and presentation, where students constructed and presented their solutions; and (5) problem analysis and evaluation, where students reflected on their learning process and evaluated the effectiveness of their solutions. These stages facilitated active engagement, collaborative learning, and the application of interdisciplinary STEM knowledge [10]–[13].

E. Data Analysis

Descriptive and inferential statistical analyses were conducted using SPSS version 21.0. Descriptive statistics, including mean scores and standard deviations, were used to summarize students' problem-solving performance before and after the intervention. Prior to hypothesis testing, assumption tests were conducted to assess data normality using the Shapiro–Wilk test and variance homogeneity using the F-test.

To determine the effectiveness of the STEM-based PBL intervention, a paired-samples t-test was performed to compare pretest and posttest scores. Additionally, effect size analysis was conducted to evaluate the magnitude of the intervention's impact on students' problem-solving abilities. Statistical significance was determined at the 0.05 level. This analytical approach enabled both statistical and practical interpretation of the instructional intervention's effectiveness.

Results and Discussion

A. Participants and Pretest–Posttest Outcomes

This study involved 22 eighth-grade students from SMPN 1 Satap Wara as research subjects. To examine the effect of STEM-based learning on students' science problem-solving skills, pretest and posttest instruments were administered. Pretest scores ranged from 13 to 40, with a mean of 19.00 and a standard deviation of 8.429. Posttest scores improved substantially, ranging from 40 to 80, with a mean of 51.41 and a standard deviation of 8.534. See Table 1.

Table 1. Descriptive Statistics of Pretest and Posttest Scores (N = 22)

	N	Minimum	Maximum	Mean	Std. Deviation
Pretest	22	13	40	19.00	8.429
Postest	22	40	80	51.41	8.534
Valid N (listwise)	22				

Despite this improvement, most students did not achieve the school's minimum competency criteria (*Kriteria Ketuntasan Minimal* or KKM). Statistical analysis (Table 2) using the paired-sample t-test revealed a significant difference ($p < 0.001$), indicating that STEM-based instruction had a substantial impact on students' problem-solving abilities [1], [14]–[15]. The effect size (ES) of 0.785 further confirms a strong influence, consistent with prior findings that STEM-based learning enhances problem-solving, critical thinking, and creativity [4], [10].

Table 2. Paired Samples Test Results Comparing Pretest and Posttest Scores (N = 22)

		Paired Differences			
		Mean	Std. Deviation	Df	Sig. (2-tailed)
Pair 1	Pretest – Posttest	33.70	17.96	43	<0.001

Prior to classroom implementation, the teacher prepared all learning materials and media to optimize the learning process. Prepared resources included validated modules, handouts, worksheets (LKPD), and PowerPoint presentations aligned with the allocated time and students' cognitive levels. Learning media such as laptops, projectors, internet access, and educational videos were tested in advance to ensure functionality. Short motivational videos were used to capture attention and stimulate students' curiosity at the beginning of lessons, in line with active learning principles [11].

B. Implementation of STEM-Based Problem-Based Learning

The findings of this study demonstrate that the integration of STEM principles with the Problem-Based Learning (PBL) framework provides a meaningful instructional approach for enhancing students' science problem-solving abilities. The structured implementation of the five-step PBL model created opportunities for students to actively engage in authentic problem-solving processes, facilitating deeper conceptual understanding and higher-order cognitive development. The observed improvement in students' performance indicates that STEM-based PBL supports not only knowledge acquisition but also the application of scientific reasoning in real-world contexts.

The first stage, problem orientation, played a critical role in stimulating students' curiosity and cognitive engagement. The use of contextual video cases depicting digestive system disorders provided an authentic entry point for inquiry, encouraging students to formulate questions and explore causal relationships. This aligns with constructivist learning theory, which emphasizes the importance of activating prior knowledge and engaging students in meaningful problem contexts to promote deeper learning [10]–[11]. By situating learning within relevant and relatable scenarios, students were able to connect theoretical concepts with practical applications, thereby strengthening their analytical and interpretive skills.

The student organization stage further contributed to the development of collaborative problem-solving competencies. By working in small groups and focusing on specific digestive organs, students engaged in shared inquiry and knowledge construction. Collaborative learning environments have been shown to enhance critical thinking, communication, and social interaction, as students exchange ideas, negotiate understanding, and collectively solve problems [12]. This collaborative process reflects the interdisciplinary nature of STEM education, where problem-solving requires the integration of diverse perspectives and collective reasoning.

During the guided investigation stage, students actively collected, analyzed, and interpreted information with structured teacher facilitation. This stage was essential in promoting inquiry-based learning, allowing students to independently explore scientific concepts while receiving appropriate instructional scaffolding. Teacher guidance ensured that

students remained focused on learning objectives and applied scientific reasoning effectively, supporting the development of analytical and evaluative thinking skills [3], [12]. This finding supports prior research indicating that guided inquiry enhances students' ability to construct knowledge and apply problem-solving strategies in STEM learning environments.

The solution development stage enabled students to synthesize their findings and communicate their conclusions through structured worksheets and group discussions. This process fostered metacognitive awareness, as students reflected on their reasoning and evaluated the effectiveness of their proposed solutions. Communication and presentation activities further reinforced students' conceptual understanding and strengthened their ability to articulate scientific ideas clearly and logically [13]. These skills are essential components of STEM competency, as effective problem-solving requires not only conceptual understanding but also the ability to communicate and justify solutions.

The final stage, problem analysis and evaluation, provided opportunities for reflection, feedback, and knowledge consolidation. By presenting their findings and receiving peer and teacher feedback, students engaged in evaluative thinking and self-assessment. This reflective process enhanced students' ability to identify strengths and limitations in their reasoning, promoting continuous improvement in problem-solving performance [13]. Reflection is a key element of meaningful learning, as it enables students to internalize knowledge and develop transferable cognitive skills applicable across scientific domains.

The overall improvement in students' problem-solving abilities observed in this study is consistent with prior research demonstrating the effectiveness of STEM-based instruction in enhancing scientific literacy, critical thinking, and student engagement [2], [4], [7], [16]. STEM-based learning environments encourage active participation, interdisciplinary thinking, and authentic problem-solving, all of which contribute to deeper learning outcomes. Furthermore, the integration of technology and multimedia resources enhanced students' engagement and motivation, creating a dynamic and interactive learning environment that supports diverse learning styles [5]–[6].

Despite these positive outcomes, several implementation challenges were identified. Limited instructional time constrained the depth of investigation and discussion, potentially affecting the extent to which students could fully explore complex problems. Additionally, variations in students' attention, prior knowledge, and learning readiness influenced their level of participation and performance. These challenges highlight the importance of considering contextual factors such as instructional time allocation, teacher preparedness, and infrastructure support when implementing STEM-based instructional approaches.

From a theoretical perspective, this study reinforces the value of integrating constructivist, inquiry-based, and interdisciplinary learning principles in science education. The STEM-PBL framework provides a pedagogical model that supports active knowledge construction, collaborative learning, and authentic problem-solving. From a practical perspective, the findings suggest that STEM-based PBL can serve as an effective instructional strategy for improving students' science problem-solving abilities, particularly in middle school contexts. The results also underscore the need for sustained implementation, adequate instructional planning, and institutional support to maximize the effectiveness of STEM-based learning interventions.

Overall, this study contributes empirical evidence supporting the effectiveness of STEM-integrated Problem-Based Learning in enhancing students' science problem-solving abilities and preparing them with essential competencies required for 21st-century learning. See Table 3 for the summary.

Table 3. Forms of Cultural Integration within the Living Curriculum

Form of Cultural Integration	Implementation Context	Meaning within the Living Curriculum
Integration in daily activities	Congregational prayer, etiquette, and Quran recitation	Daily PAI practices cultivate discipline, togetherness, leadership, etiquette, and Quranic literacy through congregational prayer, greetings, teacher respect, tilawah, and memorization as sustained learning cultures rooted in social worship values consistently.
Integration in Islamic boarding school traditions	Khataman, manaqiban, shalawat, yellow books	Pesantren traditions animate history, spirituality, and prophetic love through khataman, manaqiban, khoul, shalawat, barzanji, and yellow book studies, enabling students to learn classical texts experientially within everyday religious life contexts.
Integration in the social environment	Ro'an, simple living, bahtsul masail	Social cultures foster ukhuwah, responsibility, modesty, and deliberation through ro'an, simple living, qana'ah, zuhud, and bahtsul masail, applying fiqh and moral teachings collaboratively in communal boarding school life settings daily.
Integration in arts and cultural expression	Hadrah, marawis, qosidah, Islamic theatre	Islamic arts function as living media, integrating beauty in Islam through hadrah, marawis, qosidah, and Islamic theatre to teach prophetic stories, companions, and figures via creative, participatory student expression practices.
Integration in curriculum management	Formal–nonformal curriculum, sorogan, evaluation	Integrated curriculum management combines formal and nonformal programs through sorogan, bandongan, and practice-based assessments, fostering discipline, patience, worship leadership, and obedience to teachers aligned with holistic Islamic education goals sustainably.

Conclusion

This study demonstrates that STEM-based Problem-Based Learning (PBL) is an effective instructional approach for improving students' science problem-solving abilities. The

results showed a significant increase in students' mean scores from 19.00 in the pretest to 51.41 in the posttest, with a large effect size (ES = 0.785), indicating strong practical impact. These findings confirm that integrating STEM principles with PBL supports students in applying scientific concepts to real-world problems and enhances their analytical and reasoning skills.

In addition to improving problem-solving performance, the STEM-PBL approach promoted active learning, critical thinking, and collaboration. Through authentic problem contexts and guided investigation, students engaged more deeply in the learning process and developed essential competencies required for 21st-century education. However, some students did not reach the minimum competency threshold, suggesting the need for differentiated instruction and sustained implementation to support diverse learning needs.

This study contributes empirical evidence supporting the effectiveness of STEM-integrated PBL, particularly in middle school science contexts. Future research should involve larger samples, extended intervention periods, and diverse educational settings to strengthen the generalizability of findings and further examine the long-term impact of STEM-based instructional approaches on students' problem-solving abilities and scientific literacy.

Conflict of Interest

The authors declare no conflict of interest.

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