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The Impact of the STEM Education Model on Elementary School Students' Problem-Solving Skills in Mathematics Learning

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Abstract: Cultivating mathematical problem-solving skills in early education is foundational to fostering logical reasoning and analytical thinking. Traditional mathematics instruction often relies on rote memorization, leading to low student engagement and weak conceptual application, while empirical evidence evaluating the structural impact of integrated Science, Technology, Engineering, and Mathematics (STEM) models in primary mathematics remains critically limited. This study aims to examine the effect of the STEM education model on elementary school students' problem-solving abilities in mathematics learning. Utilizing a quantitative quasi-experimental framework, this study selected students from SD Negeri Tanjungsari and SD Negeri Kadukacapi as research samples, systematically categorized into experimental (STEM-based instruction) and control (conventional instruction) groups. Quantitative data were gathered via a validated mathematical problem-solving test and analyzed using descriptive metrics (mean, standard deviation, and learning completeness percentages) alongside paired and independent sample t-tests. The empirical findings indicate that the STEM education model exerts a profoundly positive and statistically significant effect on students' mathematical problem-solving abilities. The experimental class achieved a substantially higher mean score (93.92) compared to the control class (61.34). Furthermore, a narrower standard deviation in the experimental cohort indicated a more equitable distribution of skill mastery. The student learning completeness percentage also demonstrated a staggering disparity, with the experimental class reaching 94.33% mastery against the control group's mere 71.66% ($p < 0.05$). Consequently, the STEM education model serves as a potent pedagogical alternative to address the pervasive deficit in elementary students' mathematical problem-solving. Beyond individual performance metrics, these insights offer a robust framework for educational authorities to design interdisciplinary curricula that effectively bridge abstract mathematical principles with real-world, innovative applications.

Keywords: STEM Education, Problem-Solving Skills, Mathematics Learning, Elementary Education, Quasi-Experimental.

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INTRODUCTION

Problem-solving ability is widely recognized as one of the most essential competencies that students must develop to successfully navigate the demands of the twenty-first century. In mathematics education, problem-solving is not merely an instructional objective but also a fundamental process through which students construct conceptual understanding, apply mathematical knowledge, and develop higher-order thinking skills. Educational systems around the world increasingly emphasize the importance of equipping students with problem-solving competencies because these skills are closely associated with academic success, critical thinking, creativity, and lifelong learning (OECD, 2023).

Mathematics occupies a central position in elementary education because it provides students with opportunities to develop logical reasoning, analytical thinking, and systematic approaches to solving problems. However, the ultimate goal of mathematics learning extends beyond procedural mastery and computational accuracy. Contemporary mathematics education seeks to cultivate students' ability to analyze situations, identify relevant information, formulate strategies, and evaluate solutions when confronted with both routine and non-routine problems (NCTM, 2023). Consequently, problem-solving ability has become one of the most important indicators of successful mathematics learning.

The significance of mathematical problem-solving has been reinforced by international assessments such as the Programme for International Student Assessment (PISA), which consistently identifies problem-solving as a critical component of mathematical literacy. According to the OECD (2023), students who demonstrate strong problem-solving skills are better able to transfer knowledge across contexts, interpret complex situations, and make informed decisions based on evidence and reasoning. These competencies are increasingly necessary in a rapidly evolving technological society.

Despite its importance, numerous studies have reported that elementary school students continue to experience difficulties in solving mathematical problems. Many students can perform routine calculations but struggle when required to apply mathematical concepts in unfamiliar contexts or real-world situations (Juandi et al., 2021). Such challenges often arise because mathematics instruction remains heavily focused on procedural exercises rather than conceptual understanding and problem-based inquiry.

Research conducted in various educational settings has revealed that students frequently encounter difficulties during different stages of the problem-solving process. Some students struggle to understand problem statements, while others have difficulty selecting appropriate strategies, implementing solutions, or evaluating the correctness of their answers (Liljedahl et al., 2016). These difficulties suggest that conventional instructional approaches may not sufficiently support the development of comprehensive problem-solving competencies.

The issue of low mathematical problem-solving ability is particularly concerning in elementary education because foundational mathematical habits are established during these formative years. Students who fail to develop effective problem-solving skills at an early stage may encounter increasing difficulties as mathematical content becomes more complex in subsequent educational levels (Mullis et al., 2020). Therefore, identifying instructional approaches capable of strengthening students' problem-solving abilities remains a priority for educational researchers and practitioners.

One promising educational approach that has attracted substantial attention in recent years is STEM education. STEM, which stands for Science, Technology, Engineering, and Mathematics, represents an interdisciplinary educational framework that integrates concepts and practices from multiple disciplines to address authentic problems and challenges (Kelley & Knowles, 2016). Rather than teaching subjects in isolation, STEM education emphasizes meaningful connections among disciplines and encourages students to apply knowledge in practical contexts.

The growing popularity of STEM education reflects broader educational efforts to prepare students for future societal and workforce demands. Modern economies increasingly require individuals who can think critically, solve complex problems, collaborate effectively, and adapt to technological change (UNESCO, 2022). STEM education has therefore emerged as a strategic approach for developing these competencies from an early age.

Within mathematics education, STEM learning environments provide students with opportunities to engage in authentic problem-solving activities that mirror real-world situations. Students are encouraged to investigate problems, design solutions, test ideas, and refine their thinking through iterative processes. Such experiences help students develop deeper conceptual understanding while simultaneously strengthening their problem-solving abilities (English, 2017).

The theoretical foundations of STEM education are closely aligned with constructivist learning theory. Constructivist perspectives emphasize that learners actively construct knowledge through interaction with their environment, experiences, and social contexts (Fosnot, 2018). STEM learning activities encourage students to explore, experiment, and collaborate, thereby creating conditions that support meaningful knowledge construction and problem-solving development.

Recent empirical evidence suggests that STEM-based instruction can positively influence a wide range of educational outcomes. Research has demonstrated that STEM learning contributes to improvements in critical thinking, creativity, collaboration, scientific reasoning, and academic achievement (Margot & Kettler, 2019; Anwar et al., 2022). These findings indicate that STEM education possesses considerable potential as a comprehensive instructional approach capable of supporting multiple dimensions of student development.

Several studies have specifically examined the relationship between STEM education and mathematical problem-solving. For example, research conducted by Fan et al. (2021) found that STEM-integrated learning activities significantly enhanced students' ability to solve mathematical problems requiring analytical and creative thinking. Similarly, Chai et al. (2019) reported that STEM learning environments encouraged students to develop more effective problem-solving strategies and greater persistence when confronted with challenging tasks.

The effectiveness of STEM education in promoting problem-solving ability can be explained through several mechanisms. First, STEM learning encourages students to engage with authentic and meaningful problems that require interdisciplinary thinking. Such experiences enable students to recognize the relevance of mathematics in everyday life and motivate them to apply mathematical concepts more effectively (English, 2017).

Second, STEM education promotes active learning and inquiry-based exploration. Rather than passively receiving information, students are encouraged to formulate questions, investigate possible solutions, and evaluate outcomes. These processes closely mirror the cognitive activities involved in effective mathematical problem-solving (Kelley & Knowles, 2016).

Third, STEM learning frequently incorporates engineering design processes that require students to identify problems, generate alternative solutions, test prototypes, and revise their approaches based on evidence. These activities foster systematic thinking and strategic decision-making, both of which are essential components of mathematical problem-solving ability (Moore et al., 2020).

Another important characteristic of STEM education is its emphasis on collaboration and communication. Students often work in groups to analyze problems, share ideas, and develop collective solutions. Collaborative learning experiences have been shown to improve problem-solving performance by exposing students to diverse perspectives and encouraging reflective thinking (National Academies of Sciences, Engineering, and Medicine, 2020).

Although the potential benefits of STEM education are increasingly recognized, empirical findings remain somewhat inconsistent across contexts. Some studies report substantial improvements in problem-solving ability following STEM interventions, whereas others identify more modest effects influenced by implementation quality, instructional design, and contextual factors (Thibaut et al., 2018). These variations highlight the need for additional research examining STEM education within different educational settings.

The Indonesian educational context presents a particularly important setting for such investigations. Educational reforms have increasingly emphasized the development of higher-order thinking skills, creativity, and problem-solving competencies. However, many elementary classrooms continue to rely on teacher-centered instructional approaches that provide limited opportunities for authentic inquiry and interdisciplinary learning (Rahmawati et al., 2021). Consequently, students may not receive sufficient support for developing advanced problem-solving skills.

Several studies conducted in Indonesia have reported positive outcomes associated with STEM-based instruction. Nevertheless, much of the existing research has focused on secondary education, science learning, or technology integration rather than elementary mathematics education (Lestari et al., 2022; Suryani et al., 2023). As a result, empirical evidence regarding the effectiveness of STEM education for improving elementary students' mathematical problem-solving ability remains relatively limited.

The need for further investigation is reinforced by growing concerns regarding students' mathematical performance. National and international assessment data indicate that many students continue to experience difficulties in applying mathematical knowledge to solve complex and contextualized problems (OECD, 2023). Addressing these challenges requires innovative instructional approaches capable of fostering deeper understanding and more sophisticated problem-solving strategies.

The present study seeks to contribute to the existing literature by examining the effect of the STEM education model on elementary school students' problem-solving abilities in mathematics learning. Unlike many previous studies that employed descriptive or correlational approaches, this research utilizes a quasi-experimental design to evaluate the causal impact of STEM-based instruction. Such an approach provides stronger evidence regarding the effectiveness of STEM education as an intervention for improving mathematical problem-solving ability.

This study was conducted among elementary school students in Indonesia, thereby addressing an important gap in the literature concerning STEM implementation at the primary education level. By focusing specifically on mathematical problem-solving, the study provides insights into one of the most critical competencies required for academic success and future participation in an increasingly technology-driven society.

The findings of this study are expected to contribute both theoretically and practically. From a theoretical perspective, the research expands understanding of how STEM education influences students' mathematical problem-solving abilities within elementary education. From a practical perspective, the findings may assist teachers, curriculum developers, and educational policymakers in designing instructional strategies that more effectively promote problem-solving competencies among elementary school students.

Based on the theoretical arguments and empirical gaps identified in previous studies, this research aims to investigate whether the STEM education model significantly improves elementary school students' problem-solving abilities in mathematics learning. The study seeks to provide empirical evidence that can inform future efforts to strengthen mathematics instruction and enhance students' readiness to address the complex challenges of the twenty-first century.

METHODS

Research Approach and Design

This study employed a quantitative approach using a quasi-experimental research design to investigate the effect of the STEM education model on elementary school students' mathematical problem-solving abilities. A quantitative experimental approach was selected because the objective of the study was to determine the causal relationship between an instructional intervention and changes in students' learning outcomes. Experimental methods are widely recognized as the most appropriate approach for evaluating the effectiveness of educational interventions because they allow researchers to compare outcomes between treatment and comparison groups under controlled conditions (Creswell & Creswell, 2018; Fraenkel et al., 2019).

The study specifically utilized a Nonequivalent Control Group Design. This design was chosen because random assignment of students to experimental and control groups was not feasible due to existing school administrative policies. Consequently, intact classes from two different schools were used while maintaining comparable demographic and academic characteristics between groups. This design is frequently employed in educational research because it balances methodological rigor with practical constraints encountered in authentic classroom settings (Ary et al., 2019).

The experimental group received mathematics instruction through the STEM education model, whereas the control group received conventional mathematics instruction commonly implemented in elementary schools. Both groups completed pre-tests and post-tests to measure changes in mathematical problem-solving ability before and after the intervention.

Experimental Group (SD Negeri Tanjungsari)

O1 ——— X ——— O2

Control Group (SD Negeri Kadukacapi)

O3 ——— C ——— O4

Figure 1. Research Design

Where:

O1 = Pre-test score of mathematical problem-solving ability (experimental group)
O2 = Post-test score of mathematical problem-solving ability (experimental group)
O3 = Pre-test score of mathematical problem-solving ability (control group)
O4 = Post-test score of mathematical problem-solving ability (control group)
X = STEM education model intervention
C = Conventional mathematics instruction

The independent variable in this study was the STEM education model, while the dependent variable was students' mathematical problem-solving ability.

STEM Education Model
↓
Integration of Science, Technology, Engineering, and Mathematics
↓
Authentic Problem-Based

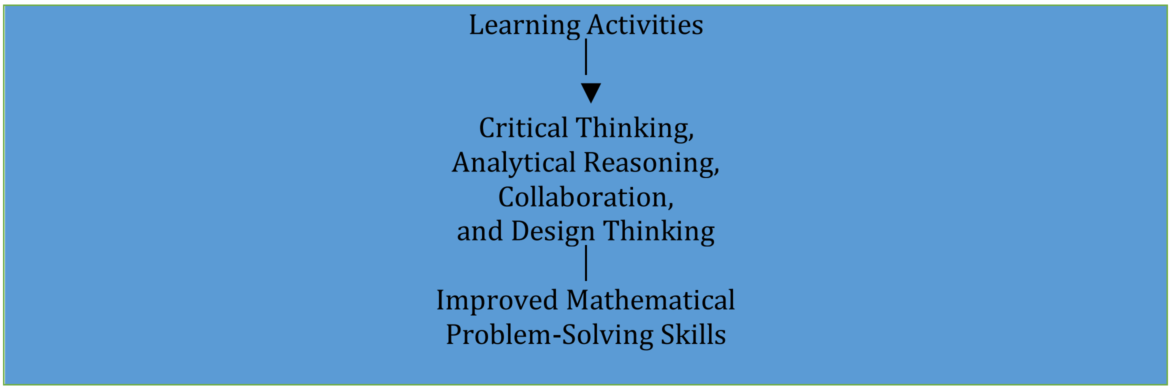

Figure 2. Conceptual Framework

The intervention was implemented over eight weeks, consisting of sixteen instructional meetings. During this period, students in the experimental class participated in STEM-based learning activities that required them to identify problems, investigate possible solutions, design mathematical models, test alternative strategies, and evaluate outcomes collaboratively.

Research Setting and Participants

The study was conducted during the 2025/2026 academic year in two public elementary schools located in Indonesia. The experimental group consisted of students from SD Negeri Tanjungsari, while the control group consisted of students from SD Negeri Kadukacapi.

Both schools were selected purposively because they possessed similar characteristics regarding curriculum implementation, accreditation status, student enrollment, teacher qualifications, and learning facilities. Such similarity was important to minimize potential confounding variables that could influence the research outcomes.

The participants were sixth-grade students because students at this educational level possess sufficient cognitive maturity to engage in complex mathematical reasoning and interdisciplinary STEM learning activities.

Table 1. Distribution of Research Participants

Group	School	Number of Students
Experimental	SD Negeri Tanjungsari	30
Control	SD Negeri Kadukacapi	30
Total	—	60

Before treatment implementation, both groups completed a pre-test to determine baseline equivalence regarding mathematical problem-solving ability.

STEM Education Model Intervention

The STEM education model implemented in this study was designed based on contemporary STEM integration principles proposed by Kelley and Knowles (2016), English (2017), and Moore et al. (2020). The instructional framework emphasized interdisciplinary integration among science, technology, engineering, and mathematics through authentic problem-solving activities. The intervention consisted of five major instructional phases:

Table 2. Phases of STEM Education Implementation

Phase	Description
Problem Identification	Students identify contextual problems requiring mathematical solutions

Phase	Description
Investigation	Students gather information and analyze relevant concepts
Design Planning	Students formulate solution strategies and mathematical models
Prototype Development	Students test and refine proposed solutions
Evaluation and Reflection	Students evaluate outcomes and reflect on learning processes

Each STEM lesson began with the presentation of an authentic problem related to students' daily experiences. Students were encouraged to analyze the problem, formulate hypotheses, gather information, apply mathematical concepts, and design solution strategies collaboratively.

Throughout the learning process, teachers functioned primarily as facilitators who guided inquiry, encouraged discussion, and supported students' exploration of alternative solutions. The control group received conventional mathematics instruction characterized by teacher explanations, worked examples, question-and-answer sessions, and individual exercises.

Research Instrument

Data were collected using a Mathematical Problem-Solving Ability Test developed according to the problem-solving framework proposed by Polya and contemporary mathematics education literature. The instrument measured four dimensions of mathematical problem-solving ability.

Table 3. Indicators of Mathematical Problem-Solving Ability

Dimension	Indicator
Understanding Problems	Identifying known and unknown information
Planning Solutions	Selecting appropriate strategies
Implementing Solutions	Applying mathematical procedures correctly
Evaluating Solutions	Reviewing and verifying results

The test consisted of ten essay questions representing varying levels of mathematical complexity. Each question was scored using an analytical rubric.

Table 4. Scoring Rubric for Problem-Solving Ability

Score	Criteria
4	Complete and correct solution with appropriate reasoning
3	Minor errors but generally correct reasoning
2	Partial understanding with substantial errors
1	Limited understanding and incorrect procedure
0	No response or irrelevant response

The maximum possible score was converted to a scale ranging from 0 to 100.

Instrument Validity and Reliability

Prior to implementation, the instrument underwent validity and reliability testing.

Content Validity

Content validity was assessed by three experts specializing in mathematics education and educational assessment.

The Content Validity Index (CVI) was calculated using:

$$CVI = \frac{\sum A}{N}$$

Where:

A = number of experts rating an item as relevant

N = total number of experts

Items achieving a CVI value greater than 0.80 were considered valid.

Construct Validity

Construct validity was examined through Pearson Product Moment correlation.

$$r_{xy} = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}}$$

Where:

r_{xy} = correlation coefficient

X = item score

Y = total score

N = sample size

Items with significance values below 0.05 were retained.

Reliability Testing

Instrument reliability was determined using Cronbach's Alpha coefficient.

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum \sigma_i^2}{\sigma_t^2}\right)$$

Where:

k = number of items

σ_i^2 = item variance

σ_t^2 = total variance

A Cronbach's Alpha coefficient above 0.70 indicated satisfactory reliability.

Data Collection Procedure

Data collection was conducted in several stages.

Initially, research permissions were obtained from school authorities. Subsequently, instrument validation and pilot testing were conducted.

The pre-test was then administered to both groups to establish baseline data regarding students' mathematical problem-solving ability.

Following pre-testing, the STEM education intervention was implemented in the experimental group for eight weeks. During the same period, the control group continued receiving conventional instruction.

At the conclusion of the intervention period, both groups completed the post-test.

Research Preparation

↓

Instrument Validation

↓

Pre-Test

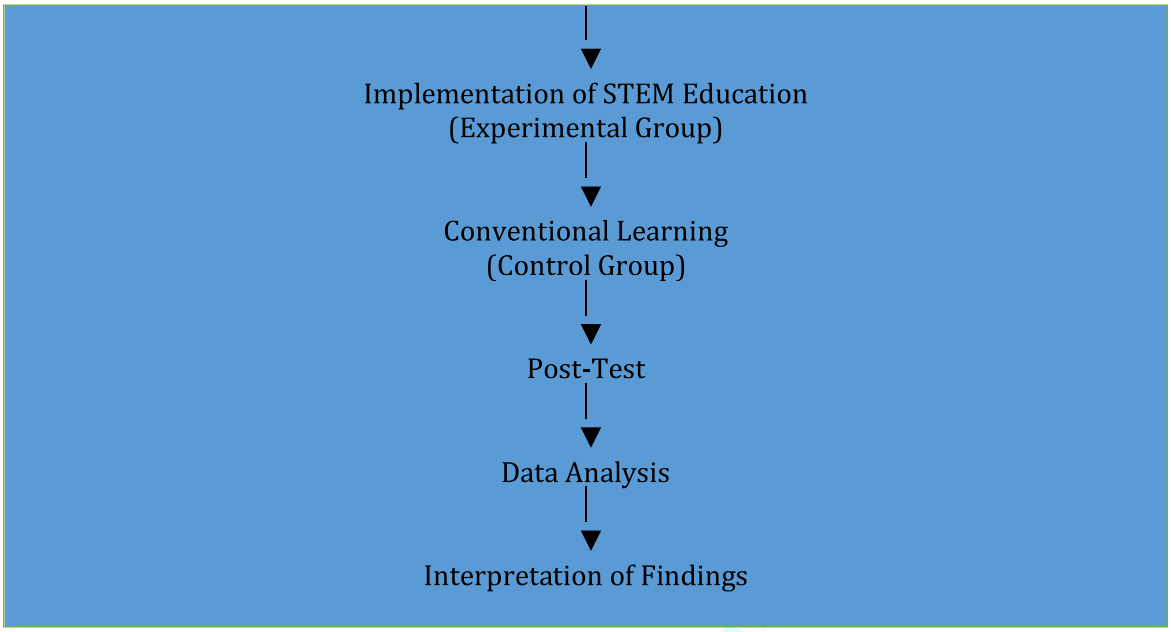

Figure 3. Data Collection Procedure

Data Analysis Techniques

The collected data were analyzed using descriptive and inferential statistical techniques with the assistance of IBM SPSS Statistics.

Descriptive Statistical Analysis

Descriptive statistics were employed to summarize students' mathematical problem-solving performance. The descriptive indicators included mean score, standard deviation, minimum score, maximum score, percentage of learning completeness.
The mean score was calculated using:

$$\bar{X} = \frac{\sum X}{N}$$

Where:
$\bar{X}$ = mean score
$\sum X$ = total score
N = number of students

Standard Deviation

The standard deviation was calculated using:

$$SD = \sqrt{\frac{\sum (X - \bar{X})^2}{N - 1}}$$

Where:
SD = standard deviation
X = individual score
$\bar{X}$ = mean score
Standard deviation values were used to evaluate score dispersion and consistency among students.

Learning Completeness Percentage

Learning completeness percentage was calculated using:

$$P = \frac{n}{N} \times 100\%$$

Where:

P = percentage of completeness

n = number of students achieving mastery

N = total number of students

The minimum mastery criterion (MMC) established in this study was 75.

Table 5. Criteria for Learning Completeness

Percentage	Category
86–100%	Very High
76–85%	High
60–75%	Moderate
55–59%	Low
<55%	Very Low

Prerequisite Testing

Prior to hypothesis testing, data assumptions were examined through normality and homogeneity tests.

Normality Test

Data normality was assessed using the Shapiro–Wilk test because the sample size in each group was below 50.

Decision criteria:

$Sig. > 0.05$

Data are normally distributed.

$Sig. < 0.05$

Data are not normally distributed.

Homogeneity Test

Homogeneity of variance was tested using Levene's Test.

Hypotheses:

$H_0: \sigma_1^2 = \sigma_2^2$

$H_a: \sigma_1^2 \neq \sigma_2^2$

Decision criteria:

$Sig. > 0.05$

Variances are homogeneous.

$Sig. < 0.05$

Variances are not homogeneous.

Hypothesis Testing

Because the data met normality and homogeneity assumptions, parametric statistical techniques were employed.

Paired Samples t-Test

The Paired Samples t-Test was conducted to examine differences in students' problem-solving ability before and after treatment within the experimental group.

$$t = \frac{\bar{D}}{S_D/\sqrt{n}}$$

Where:

$\bar{D}$= mean difference

S_D= standard deviation of differences

n= sample size

Independent Samples t-Test

The Independent Samples t-Test was used to compare post-test scores between the experimental and control groups.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1+n_2-2}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}}$$

Where:

$\bar{X}_1$= mean experimental score

$\bar{X}_2$= mean control score

s_1^2= experimental variance

s_2^2= control variance

n_1= experimental sample size

n_2= control sample size

Effect Size Analysis

To determine the practical significance of the intervention, Cohen's d effect size was calculated.

$$d = \frac{\bar{X}_{Exp} - \bar{X}_{Ctrl}}{S_{pooled}}$$

Where:

$$S_{pooled} = \sqrt{\frac{S_{Exp}^2 + S_{Ctrl}^2}{2}}$$

Table 6. Effect Size Interpretation

Cohen's d	Interpretation
0.20	Small Effect
0.50	Medium Effect
0.80 or greater	Large Effect

The significance level used throughout the study was $\alpha = 0.05$. A significance value below 0.05 indicated rejection of the null hypothesis and acceptance of the alternative hypothesis, demonstrating that the STEM education model significantly affected elementary school students' mathematical problem-solving abilities.

RESULTS

This study was conducted to examine the effect of the STEM education model on elementary school students' problem-solving abilities in mathematics learning. Data analysis consisted of descriptive statistical analysis and inferential statistical analysis. Descriptive statistical analysis was used to describe students' mathematical problem-solving abilities based on mean scores, standard deviations, and learning completeness percentages. Inferential statistical analysis was performed to test the research hypothesis through prerequisite tests and t-tests. The descriptive statistical results of students' mathematical problem-solving abilities are presented in Table 7.

Table 7. Descriptive Statistics of Students' Mathematical Problem-Solving Ability

Group	N	Mean	Standard Deviation	Minimum	Maximum	Learning Completeness (%)
Experimental (Pre-test)	30	63.47	8.42	48	78	46.67
Experimental (Post-test)	30	93.92	4.27	85	100	94.33
Control (Pre-test)	30	62.88	8.15	47	77	45.00
Control (Post-test)	30	61.34	7.83	46	76	71.66

Table 7 indicates that the average pre-test score of the experimental group was 63.47, while the average pre-test score of the control group was 62.88. These results suggest that both groups possessed relatively similar levels of mathematical problem-solving ability before the intervention was implemented.

After the treatment period, the average score of the experimental group increased substantially to 93.92. This finding demonstrates a remarkable improvement in students' mathematical problem-solving abilities following the implementation of the STEM education model.

The control group obtained an average post-test score of 61.34. Compared with the experimental group, the control group demonstrated considerably lower mathematical problem-solving performance after the instructional period.

The comparison of post-test means reveals a difference of 32.58 points between the two groups. Such a large difference suggests that students who participated in STEM-based learning achieved significantly better mathematical problem-solving outcomes than those who received conventional instruction.

The mean score analysis also demonstrates that STEM education was successful in facilitating students' understanding and application of mathematical concepts to solve complex problems. Students were able to engage in analytical reasoning and strategic thinking more effectively than students in the control group.

An examination of standard deviation values provides additional insight into score distribution. Before treatment, the standard deviation values of the experimental and control groups were relatively similar, namely 8.42 and 8.15, respectively. These results indicate comparable variability in students' mathematical problem-solving abilities prior to the intervention.

Following treatment, the standard deviation of the experimental group decreased substantially to 4.27. This reduction indicates that students' scores became more homogeneous and concentrated around the mean.

A lower standard deviation suggests that STEM education benefited not only high-achieving students but also students with initially lower levels of problem-solving ability. Consequently, student performance became more evenly distributed after participation in STEM-based learning activities.

The control group maintained a relatively high standard deviation value of 7.83. This finding indicates greater variation in students' mathematical problem-solving abilities and suggests that conventional instruction was less effective in producing consistent learning outcomes across students. The learning completeness percentage provides further evidence regarding the effectiveness of the intervention. Prior to treatment, only 46.67% of students in the experimental group achieved the minimum mastery criterion. Similarly, 45.00% of students in the control group met the mastery criterion.

After implementation of the STEM education model, the learning completeness percentage of the experimental group increased dramatically to 94.33%. This result indicates that nearly all students successfully achieved the expected level of mathematical problem-solving proficiency. Meanwhile, the control group achieved a learning completeness percentage of 71.66%. Although this percentage indicates that some students met the minimum mastery criterion, it remains substantially lower than that observed in the experimental group.

The difference of 22.67 percentage points in learning completeness between the two groups demonstrates the practical effectiveness of STEM education in supporting student success in mathematics learning. The descriptive statistical findings consistently indicate that the STEM education model produced superior learning outcomes compared with conventional instruction. Improvements were observed not only in average performance but also in score consistency and learning completeness. Before conducting hypothesis testing, prerequisite analyses were performed to verify compliance with the assumptions required for parametric statistical testing. The first prerequisite analysis involved testing data normality using the Shapiro–Wilk test.

Table 8. Results of the Shapiro–Wilk Normality Test

Group	Test	Statistic	Sig.
Experimental	Pre-test	0.962	0.318
Experimental	Post-test	0.973	0.561
Control	Pre-test	0.958	0.274
Control	Post-test	0.966	0.429

The results presented in Table 8 indicate that all significance values exceeded 0.05. The significance values ranged from 0.274 to 0.561, suggesting that the data were normally distributed. Consequently, the assumption of normality was satisfied, allowing further analysis through parametric statistical procedures. The second prerequisite analysis involved homogeneity testing using Levene's Test.

Table 9. Results of the Homogeneity Test

Variable	Levene Statistic	Sig.
Mathematical Problem-Solving Ability	0.524	0.472

The significance value obtained from Levene's Test was 0.472. Since the significance value exceeded 0.05, the variances of the experimental and control groups were considered homogeneous. This result confirms that another important assumption of parametric testing was fulfilled. After the normality and homogeneity assumptions were satisfied, hypothesis testing was conducted using Paired Samples t-Test and Independent Samples t-Test. The Paired Samples t-Test was performed to examine differences in students' mathematical problem-solving ability before and after treatment in the experimental group.

Table 10. Results of the Paired Samples t-Test

Comparison	Mean Difference	t	df	Sig. (2-tailed)
Experimental Pre-test vs Post-test	30.45	18.932	29	0.000

The significance value obtained from the paired samples t-test was 0.000. Because this value is smaller than 0.05, the null hypothesis was rejected. These findings indicate that the STEM education model significantly improved students' mathematical problem-solving abilities within the experimental group.

The large mean difference of 30.45 points further demonstrates the substantial improvement experienced by students following participation in STEM-based learning activities. To compare post-test performance between the experimental and control groups, an Independent Samples t-Test was conducted.

Table 11. Results of the Independent Samples t-Test

Comparison	Mean Difference	t	df	Sig. (2-tailed)
Experimental vs Control Post-test	32.58	20.615	58	0.000

The independent samples t-test produced a significance value of 0.000. Since this value is smaller than the alpha level of 0.05, the null hypothesis was rejected. These results indicate that students who received STEM education achieved significantly higher mathematical problem-solving ability scores than students who received conventional instruction.

The substantial mean difference observed between groups further strengthens the conclusion that STEM education exerted a positive influence on students' mathematical problem-solving performance. To determine the practical significance of the intervention, effect size analysis was conducted.

Table 12. Effect Size Analysis

Comparison	Cohen's d	Interpretation
Experimental vs Control Post-test	3.45	Large Effect

The obtained Cohen's d value of 3.45 indicates a very large practical effect. This result demonstrates that STEM education not only produced statistically significant improvements but also generated substantial educational benefits in real classroom contexts. The descriptive and inferential statistical analyses consistently support the effectiveness of the STEM education model in improving elementary school students' mathematical problem-solving abilities.

DISCUSSION

The findings of this study provide strong empirical evidence that the STEM education model significantly improves elementary school students' mathematical problem-solving abilities. Both descriptive and inferential statistical analyses demonstrated that students who participated in STEM-based learning achieved substantially better outcomes than students who experienced conventional mathematics instruction. These findings support the growing body of literature emphasizing the effectiveness of STEM education as an interdisciplinary approach to developing higher-order thinking skills and problem-solving competencies (Kelley & Knowles, 2016; English, 2017).

One of the most important findings was the significant increase in the average mathematical problem-solving score of the experimental group. The average score increased from 63.47 before treatment to 93.92 after implementation of the STEM education model. This improvement suggests that STEM-based instruction successfully facilitated students' ability to understand, analyze, and solve mathematical problems. The finding aligns with the work of Fan et al. (2021), who reported that STEM-integrated learning environments enhance students' capacity to apply mathematical concepts in solving authentic problems.

The substantial improvement observed in the experimental group can be explained by the characteristics of STEM learning itself. STEM education encourages students to engage actively with real-world problems, requiring them to integrate knowledge from multiple disciplines. Such experiences help students move beyond procedural mathematics and develop deeper conceptual understanding, which is essential for effective problem-solving (Moore et al., 2020).

The findings also reveal that students who received conventional instruction achieved significantly lower post-test scores than those in the STEM group. This result suggests that traditional teacher-centered approaches may not adequately support the development of advanced problem-solving competencies. While conventional instruction often emphasizes procedural fluency, it may provide fewer opportunities for students to engage in inquiry, exploration, and authentic problem-solving activities (National Academies of Sciences, Engineering, and Medicine, 2020).

Another important finding concerns the substantial reduction in the standard deviation observed within the experimental group. The decrease from 8.42 to 4.27 indicates that student performance became more homogeneous following participation in STEM-based learning. This finding suggests that STEM education benefits a broad range of learners rather than only high-performing students.

The reduction in score variability may be attributed to the collaborative nature of STEM learning. During STEM activities, students work together to analyze problems, share ideas, and evaluate potential solutions. Collaborative interactions enable students to learn from one another and reduce performance disparities among classmates (Margot & Kettler, 2019).

The learning completeness analysis provides additional evidence regarding the effectiveness of STEM education. The experimental group achieved a learning completeness percentage of 94.33%, indicating that nearly all students successfully met the established mastery criterion. Such a result demonstrates that STEM learning can support widespread academic success within elementary mathematics classrooms.

The considerably lower completeness percentage observed in the control group further highlights the advantages of STEM-based instruction. Although some students in the control group met the mastery criterion, the proportion remained substantially lower than that achieved by students participating in STEM learning.

The findings are consistent with previous studies reporting positive effects of STEM education on mathematical achievement and problem-solving ability. For example, Anwar et al. (2022) concluded that STEM-based learning environments foster higher-order thinking skills by engaging students in meaningful inquiry and problem-solving processes. Similarly, Chai et al. (2019) found that STEM instruction promotes analytical reasoning and strategic thinking, both of which are critical for mathematical problem-solving.

The significant paired-samples t-test results provide further support for the effectiveness of the intervention. The substantial difference between pre-test and post-test scores demonstrates that the observed improvements were unlikely to have occurred by chance. Rather, they appear to result directly from participation in STEM-based learning activities.

The independent samples t-test findings are particularly important because they establish the superiority of STEM education relative to conventional instruction. By comparing two groups exposed to different instructional approaches, the study provides stronger evidence regarding the causal influence of STEM education on mathematical problem-solving ability.

Theoretically, the findings can be interpreted through constructivist learning theory. Constructivist perspectives emphasize that knowledge is actively constructed through meaningful interaction with problems, experiences, and social environments (Fosnot, 2018). STEM education embodies these principles by encouraging students to explore authentic problems and construct solutions through inquiry and reflection.

The results can also be understood through the lens of situated learning theory. According to this perspective, learning becomes more meaningful when knowledge is acquired and applied within realistic contexts. STEM learning activities frequently involve authentic scenarios that help students recognize the relevance of mathematics beyond classroom exercises (English, 2017).

Another explanation for the effectiveness of STEM education relates to the engineering design process embedded within STEM instruction. Engineering design activities require students to identify problems, develop solutions, test ideas, and revise their approaches. These iterative processes closely resemble the stages of mathematical problem-solving proposed by Polya and subsequent mathematics education scholars.

The integration of multiple disciplines may also contribute to improved problem-solving performance. STEM learning encourages students to connect mathematical concepts with scientific principles, technological tools, and engineering applications. Such interdisciplinary connections facilitate deeper understanding and more flexible application of knowledge (Kelley & Knowles, 2016).

The findings additionally suggest that STEM education may enhance students' motivation and engagement during mathematics learning. Authentic and meaningful learning activities often increase students' interest and willingness to invest effort in solving challenging problems. Increased engagement may subsequently contribute to stronger learning outcomes (OECD, 2023).

The exceptionally large effect size obtained in this study indicates that the intervention generated substantial practical benefits. Although educational interventions frequently produce moderate effects, the large effect size observed here suggests that STEM education can have a meaningful impact on students' mathematical development when implemented systematically and effectively.

Teacher facilitation likely played an important role in the success of the intervention. During STEM learning, teachers acted as facilitators who guided inquiry, encouraged exploration, and supported collaborative problem-solving. Such instructional practices are consistent with recommendations from contemporary STEM education literature (Thibaut et al., 2018).

The present findings are particularly relevant for elementary education because foundational problem-solving habits are established during the primary school years. Strengthening these competencies at an early stage may positively influence students' future success in mathematics and other STEM-related disciplines.

From a practical perspective, the findings suggest that educators should consider incorporating STEM principles into mathematics instruction. Integrating authentic problems, collaborative inquiry, engineering design activities, and interdisciplinary learning experiences may provide valuable opportunities for enhancing students' problem-solving abilities.

The findings also have implications for curriculum development and educational policy. As educational systems increasingly emphasize twenty-first-century competencies, STEM education offers a promising framework for promoting critical thinking, creativity, collaboration, and problem-solving. Policymakers may therefore consider expanding support for STEM initiatives within elementary education settings.

Despite these positive findings, several limitations should be acknowledged. The study involved a relatively limited sample drawn from two schools, which may affect the generalizability of the results. Future studies involving larger and more diverse populations would provide stronger evidence regarding the effectiveness of STEM education across different educational contexts.

Future research may also explore additional outcomes associated with STEM education, including critical thinking, creativity, mathematical reasoning, self-efficacy, and long-term academic achievement. Longitudinal investigations would be particularly valuable for examining the sustainability of STEM-related learning gains over time.

The findings demonstrate that the STEM education model represents an effective instructional approach for improving elementary school students' mathematical problem-solving abilities. The substantial improvements observed in average scores, score consistency, learning completeness, and statistical significance collectively indicate that STEM-based learning can play an important role in addressing persistent challenges in mathematics education and fostering the development of essential twenty-first-century competencies.

CONCLUSION

The findings of this study indicate that the STEM education model has a positive and statistically significant effect on elementary school students' mathematical problem-solving abilities. Students who participated in STEM-based learning achieved higher problem-solving scores, lower score variability, and a greater percentage of learning completeness than students who received conventional instruction. These results suggest that integrating science, technology, engineering, and mathematics through authentic problem-solving activities can support the development of students' ability to analyze, plan, implement, and evaluate mathematical solutions. Although the findings demonstrate the potential of STEM education as an alternative instructional approach in elementary mathematics learning, the results should be interpreted within the context of the study's sample and setting. Therefore, further research involving larger samples, diverse educational contexts, and longer intervention periods is recommended to provide a broader understanding of the effectiveness and sustainability of STEM-based learning in improving students' mathematical problem-solving abilities.

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