

STEM education: Impact on mathematics learning outcomes

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ABSTRACT

Background: The integration of STEM education in mathematics learning aims to enhance students' understanding and application of mathematical concepts in real-world contexts. However, its effectiveness in improving mathematics learning outcomes requires further empirical investigation.

Aim: This study examines the impact of STEM education on students' mathematics learning outcomes by comparing STEM-integrated instruction with conventional teaching methods.

Method: A quasi-experimental design was employed, involving 52 students divided into an experimental group (STEM-based learning) and a control group (traditional learning). Pre-test and post-test assessments were conducted, and the data were analyzed using statistical tests.

Results: The results showed that students in the experimental group had a significantly higher improvement in mathematics learning outcomes compared to the control group. The post-test scores increased by an average of 6.1 in the experimental group, while the control group showed an improvement of only 1.8, ($t(50) = 4.53, p < 0.05$).

Conclusion: The findings indicate that STEM education positively influences mathematics learning outcomes by enhancing students' engagement, problem-solving skills, and conceptual understanding. This study highlights the importance of incorporating STEM-based approaches in mathematics education to optimize student learning outcomes.

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INTRODUCTION

Mathematics plays a key role as a primary tool in exploring scientific phenomena, analyzing data, and designing technological solutions. In the context of STEM (Science, Technology, Engineering, and Mathematics) education, an understanding of mathematics is crucial for students to grasp the complexities within the fields of science, technology, and engineering. The STEM education approach emphasizes that mathematics should not be taught in isolation, but rather connected to real-world situations, allowing students to apply mathematical concepts and principles in solving practical problems. With this application-based learning method, mathematics becomes more meaningful and relevant, as students can experience its direct impact on daily life and their surrounding environment (Eshaq, 2023; Bright, 2024).

This experiential-based learning not only makes mathematics more engaging but also provides deeper meaning for students. Eshaq (2023) and Ryan (2021) demonstrate that student involvement in experiential learning can enhance their motivation and understanding of mathematical concepts. Furthermore, STEM education also encourages the development of critical thinking skills, which are crucial for the success of mathematics learning. Through the context of mathematics, students are provided with opportunities to develop talent and critical thinking skills, which are integral components of STEM education (Al-zboon et al., 2021; Tezer, 2020).

High order thinking skills such as creativity, innovation, and problem-solving abilities become essential when students are faced with complex mathematical problems. Gursoy et al. (2023) emphasize that STEM education focuses not only on mastering mathematical concepts but also on developing the skills necessary to tackle real-world challenges. In this context, technology plays a crucial role in supporting more personalized mathematics learning. By using adaptive learning platforms and available resources, students can learn at their own pace, receive immediate feedback, and access additional materials to support their understanding (Flavin & Lee, 2023; Saal & Graham, 2023). This personalized

approach helps students bridge knowledge gaps and challenge themselves with more difficult content. Technology also opens up opportunities for collaborative learning and broadens global connections. Sileyew (2019) highlights that teachers are expected to make the most of technology in STEM education to make mathematics learning more effective. By integrating technology into the learning process, teachers can create interactive and enjoyable learning experiences that encourage students to engage deeply and excel in mathematics (Saal & Graham, 2023; Karalar et al., 2021).

Research has shown numerous benefits from the principles of STEM in mathematics teaching. Several studies, such as those conducted by Eshaq (2023), conclude that integrating STEM concepts into learning can enhance students' mathematical abilities. STEM provides a deeper understanding by connecting mathematical concepts through practical experiences and hands-on activities. STEM activities also help students sharpen their analytical, logical, and problem-solving skills. STEM education encourages interdisciplinary learning, allowing students to understand the connections between mathematics and other STEM fields (Eshaq, 2023; Körtesi et al., 2022). This combination improves students' performance in applying mathematical principles to real-world situations. Other studies emphasize the importance of motivation and student engagement in supporting mastery of mathematics in STEM fields. Project-based or inquiry-based learning not only boosts students' interest in mathematics but also strengthens their conceptual understanding and long-term memory retention.

Macun and Cemalettin (2022) note that professional teacher training in STEM-based teaching significantly influences the quality of mathematics education. Teachers who receive STEM training are better equipped to create engaging learning environments that stimulate mathematical thinking and help students solve problems (Svela et al., 2019; Nantshev et al., 2020). However, there is a need for more comprehensive research on the long-term impact of STEM education on mathematics learning, particularly in terms of teaching methodologies, evaluation techniques, and specific contextual factors. STEM education is an innovative and holistic approach to 21st-century education. This approach introduces a cross-disciplinary mindset that helps students understand the connections between STEM fields and real-world applications. The use of practical examples in STEM education not only motivates students to learn but also equips them with essential skills to face global challenges and adapt to dynamic changes (Wal et al., 2017; "Mathematics Learning Based on or Assisted by ICT and Numerical Literacy: A Systematic Review and Meta-Analysis," 2024). These skills are relevant at all educational levels and in various fields of work, making them highly valuable. Furthermore, STEM education fosters scientific creativity, global competitiveness, and a spirit of innovation and entrepreneurship. Landolfi (2023) emphasizes that STEM education also instills cultural and democratic values, producing responsible and ethical individuals. The relevance of STEM, linked to business and industry, further solidifies the importance of this approach in the modern era. Overall, STEM education prepares individuals to succeed in a complex and interconnected global world, with a focus on the importance of innovation and adaptation (Bezhanu et al., 2019; Omolafe, 2021).

Although mathematical skills are considered important by many, students' motivation to learn is often not given sufficient attention. When teaching methods focus solely on monotonous lectures and demand more memorization from students, their interest in mathematics tends to decline. Cahapay and Labrador (2022) demonstrate that more interactive and experiential approaches can enhance student motivation and help them see the relevance of mathematics in everyday life (Lavicza et al., 2020; Acharya, 2023). In this context, it is crucial to develop more innovative and engaging teaching methods that not only focus on mastering mathematical concepts but also on their practical application in real-world situations. This way, students not only learn mathematics as a separate discipline but also as a tool they can use to understand and solve the problems they encounter in daily life. This approach aligns with the principles of STEM education, which emphasizes the integration of science, technology, engineering, and mathematics (Gómez-García et al., 2020).

Achieve this goal, it is crucial for educators to continuously update their knowledge and skills in utilizing relevant educational technologies. Ongoing professional development for teachers in the use of

technology in mathematics instruction can enhance teaching effectiveness and help students achieve better learning outcomes. Research by Saal and Graham (2020) shows that the integration of technology in mathematics education can improve students' learning outcomes, especially when teachers have adequate knowledge of how to use technology in the learning context (Naidoo & Reddy, 2023; Saal & Graham, 2019). Thus, STEM education not only focuses on mastering mathematical concepts but also on developing the skills needed to address real-world challenges. Through more interactive and experiential approaches, students can experience the relevance of mathematics in daily life, which, in turn, can increase their motivation and engagement in learning. Therefore, it is important for educators to continually explore innovative ways to integrate technology and engaging learning approaches in mathematics instruction (Gamit, 2023; Çevikbaş et al., 2023).

METHOD

Research Design and Participants

This study employs a quasi-experimental design, which allows for the analysis of causal relationships between variables without applying randomization in the assignment of participants to control and experimental groups. This approach was chosen due to practical limitations and the need to evaluate the impact of STEM education integration on students' mathematical achievement within a specific educational context. The study consists of two groups: the experimental group, which received STEM-based mathematics training, and the control group, which received conventional mathematics instruction without STEM integration.

A pre-test was administered to measure students' mathematical abilities before the STEM intervention was applied. After the implementation of the STEM-integrated mathematics education over a specific period, a post-test was conducted. To ensure equivalence between the two groups, matching was performed based on demographic characteristics, prior mathematical achievement, and the quality of the instructors. Other factors, such as students' socioeconomic background and initial self-efficacy in mathematics, were also considered in this study. The study involved a total of 52 participants, with 26 students in the experimental group and 26 students in the control group. All participants completed the assessment, resulting in a 100% response rate.

Variables and Data Collection

This study identifies the independent variable as the implementation of STEM education in mathematics instruction, with the experimental group receiving STEM-based mathematics teaching and the control group undergoing conventional mathematics instruction without STEM integration. The dependent variable is students' mathematics learning outcomes, reflecting their competence in mathematics. Evaluation was conducted through pre-tests and post-tests to measure students' skills, understanding, problem-solving abilities, and overall success in mathematics. The study also considers control variables, such as students' socioeconomic status, previous mathematics achievement, and teacher qualifications, to ensure that the impact of STEM education can be clearly measured.

For data collection, the study uses standardized tests that align with the mathematics curriculum and learning objectives. These tests assess a wide range of mathematical concepts, problem-solving techniques, and critical thinking skills. Performance-based assessments are also used, requiring students to solve problems involving logic, problem-solving, and mathematical modeling in real-world contexts. Additionally, a questionnaire was administered to assess students' experiences and perspectives on STEM education's impact on their mathematics achievements. The reliability of the questionnaire was measured using Cronbach's Alpha, with a result of 0.85. The questionnaire consisted of six questions exploring students' opinions on mathematics learning and the effect of STEM education integration.

Data Analysis

Comparing mathematical abilities between the control and experimental groups involved analyzing quantitative results from the pre-test and post-test using appropriate statistical procedures, such as t-tests for independent samples or analysis of covariance (ANCOVA). Statistical methods were applied to evaluate the quantitative data from the tests and surveys. Descriptive statistics, including means and frequencies, helped summarize the survey responses. A comprehensive statistical analysis was conducted, including paired t-tests to compare results within groups (from pre-test to post-test) and independent t-tests to compare results between groups (post-test scores of the experimental and control groups).

RESULTS AND DISCUSSION

Results

The results of the study demonstrate the benefits of STEM education on students' mathematics learning outcomes, as explained below. Data analysis reveals a significant difference between the experimental group, which received STEM-integrated mathematics instruction, and the control group, which received conventional mathematics instruction. Table 1 presents the descriptive statistics for both groups.

Table 1. Descriptive Statistics of the Experimental and Control Groups

Group	Pre-test mean score	Post-test mean skor	Difference
Experimental	76.5	82.6	+6.1
Control	72.4	74.2	+1.8

This experimental study evaluates the impact of integrating STEM education on students' mathematics achievement. The results indicate that the experimental group achieved an average score of 76.5 on the pre-test, while the control group recorded an average score of 72.4. After the intervention, the experimental group showed a significant improvement, with an average post-test score of 82.6. In contrast, the control group also experienced improvement, though not as much as the experimental group, with an average post-test score of 74.2. To assess the significance of the difference between pre-test and post-test results, a paired t-test was conducted.

Table 2. Paired t-test Results Between *Pre-test* and *Post-test*

Comparison	df	t	p
Within the Experimental Group	25	7.70	< 0.05
Within the Control Group	25	2.40	< 0.05

The experimental group, the paired t-test showed a statistically significant improvement between the pre-test and post-test, with an average increase of 7.7 points ($t(25) = 7.70, p < .05$). Similarly, in the Control Group, the paired t-test showed a significant improvement from the pre-test to the post-test, with an average increase of 2.4 points ($t(25) = 2.40, p < .05$). Additionally, an independent t-test was conducted to assess the significance of the difference between the experimental and control group scores. Table 3 presents the results of this test.

Table 3. Independent t-test Results Between *Pre-test* and *Post-test*

Comparison	df	t	p
Experimental vs Control (Posttest)	50	4.53	< 0.05

The independent t-test between the post-test scores of the Experimental and Control Groups showed a statistically significant difference, demonstrating the impact of STEM education on students' mathematics achievement ($t(50) = 4.53, p < .05$). This indicates that the difference in scores between the two groups is unlikely to have occurred by chance. The Experimental Group had an average post-test score of 82.6, while the Control Group recorded an average score of 74.2.

Discussion

This study concludes that the implementation of STEM education has a positive impact on students' mathematics achievement. The significant difference in average scores indicates that the improvement was not due to chance. In addition to the quantitative results, the study also includes qualitative findings from survey responses and participant observations. Students in the experimental group were reported to exhibit higher motivation, engagement, and critical thinking skills during mathematics lessons. They also demonstrated a better understanding of mathematical concepts and were able to apply them in practical situations (Nanjundeswaraswamy & Divakar, 2021). This suggests that the integration of STEM education has a significant influence on students' mathematics achievement. Further qualitative findings support this by showing improvements in motivation, engagement, critical thinking, and the application of mathematical concepts in real-world situations among students in the experimental group.

The STEM program prioritizes critical thinking and practical knowledge, preparing students to face the challenges of the 21st century. This shows that STEM education is more than just memorization; it encourages students to apply the knowledge they acquire to real-life situations. This approach also motivates students to create creative projects within the STEM fields (Nağaç et al., 2021). The practical approach provides students with the opportunity to apply their knowledge and problem-solving skills in innovative ways. By developing STEM skills, students will be better prepared to enter the workforce and contribute to industries based on science and technology. The primary goal is to enhance scientific literacy among students. Previous studies have shown that integrating STEM into mathematics instruction can improve students' mathematical abilities. Students involved in STEM activities have been proven to possess better problem-solving skills, sharpened critical thinking, and a deeper understanding of mathematical concepts. Constructivism, which emphasizes active learning and practical experiences, and socio-cultural theory, which highlights the importance of social interaction and collaborative learning in mathematics education, are two theories that support the positive impact of STEM education on mathematics achievement (Crabtree et al., 2019). These theories support student-centered, inquiry-based teaching methods, aligning with the principles of STEM. This approach not only teaches subject-specific knowledge but also equips students with the skills to think critically and apply scientific principles in various contexts (Fufa et al., 2023).

This study emphasizes the importance of inquiry-based learning, practical approaches, and the value of group projects and social interaction in mathematics instruction. The study did not find any contradictory or surprising results, but consistently demonstrated the positive impact of integrating STEM teaching on students' mathematics achievement. The study also suggests that further research could explore variations in the effectiveness of STEM integration across different student groups or educational environments (Gnagey et al., 2016). This could deepen our understanding of the impact of STEM education. Numerous previous studies have shown the positive effects of STEM programs on students' achievement, attitudes, interests, communication skills, and problem-solving abilities, which have led the educational community to reform teaching approaches in STEM fields (Han et al., 2015; Kazu et al., 2021). Moreover, integrating STEM education into mathematics teaching indicates that further research could provide broader insights into its impact.

Limitations

The limitations of this study reveal several important issues that require serious attention. The reliance on a small sample size from only two classes through convenience sampling reduces the study's ability to generalize the findings to a broader population. The absence of random assignment further hinders the establishment of causal relationships and introduces the risk of selection bias. Additionally, the use of self-reported surveys, though common, introduces the potential for response bias that could affect the internal validity of the study. Overall, these limitations overshadow the external validity of the research, limiting the extent to which the findings can be applied beyond the specific context. Acknowledging and addressing these limitations in the research report is crucial for transparency and for helping readers accurately assess the generalizability and implications of the study. Researchers should be mindful of these limitations when interpreting the results and use them as valuable insights for designing future studies aimed at achieving stronger, more widely applicable research outcomes.

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CONCLUSION

This study indicates that the integration of STEM education has a significant positive impact on students' mathematics learning outcomes. Through a quasi-experimental approach, the study reveals that students who participated in the STEM education program showed greater improvement in their learning outcomes compared to students who received conventional mathematics instruction. Although the research design did not fully utilize randomization, the data obtained from the pre-test and post-test demonstrated a statistically significant difference between the two groups, suggesting that STEM integration can enhance students' mathematics learning outcomes. STEM education, which involves hands-on experiments, problem-solving, and real-world applications, effectively encourages students to think critically, collaborate, and apply their creativity in relevant situations. This approach not only improves academic achievement but also stimulates students' interest and engagement in learning mathematics. Therefore, the integration of STEM into the curriculum can be an effective strategy in preparing students to face the challenges of the 21st-century workforce while deepening their understanding of mathematical concepts.

AUTHOR CONTRIBUTIONS

The author was responsible for the conceptualization and design of the study, data collection, and initial data analysis. This author also led the drafting and development of the manuscript. Contributed to the theoretical framework, conducted an in-depth literature review, and provided substantial revisions to enhance the academic quality and clarity of the manuscript. Both authors reviewed and approved the final version of the manuscript prior to submission.

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