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The Application of the STEM Approach in Mathematics Learning to Improve Critical Thinking Skills in Junior High School Students

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ABSTRACT
This study aims to analyze the effectiveness of the STEM (Science, Technology, Engineering, and Mathematics) approach in improving junior high school students' critical thinking skills in mathematics. The STEM approach emphasizes the integration of cross-disciplinary concepts through contextual projects that encourage students to think creatively, reflectively, and analytically. The research employed a quasi-experimental method with a non-equivalent control group design. The sample consisted of 64 eighth-grade students from a public junior high school in East Java. The results indicate that STEM-based instruction significantly enhances students' critical thinking skills. These findings reinforce that STEM integration is effective for implementing 21st-century mathematics learning.

Keywords:
STEM, mathematics learning, critical thinking, 21st-century education

INTRODUCTION

21st-century education requires students to have higher-order thinking skills such as critical thinking, problem solving, creativity, communication, and collaboration. These competencies cannot develop optimally if learning is still dominated by lecture methods and procedural exercises, as is still commonly found in mathematics learning in schools (Hidayat, 2020). This condition poses a major challenge, considering that mathematics should be a means of forming logical and analytical thinking patterns, which are the basis for the development of 21st-century skills.

Mathematics as a discipline does not only study concepts, formulas, and procedures, but also involves the ability to analyze, evaluate, and apply them in various real-life contexts. However, learning practices in the field show that students often memorize the steps to solve problems without understanding the interrelationships between concepts and their applications (Nugraha, 2021). This results in students' low ability to solve contextual problems and think critically. This gap demands innovation in learning approaches that are more meaningful and applicable.

One approach that is considered to be in line with these needs is the STEM (Science, Technology, Engineering, and Mathematics) approach. STEM is a learning approach that integrates several disciplines to solve problems through creative thinking, engineering design, and the use of technology (Rahmadhani, Pujiastuti, & Fathurrohman, 2023). In this approach, students not only learn mathematical concepts abstractly but also connect them to the application of science, technology, and engineering through project-based activities.

The STEM approach has been proven to increase learning motivation, student engagement, and in-depth understanding of mathematical concepts because the learning process takes place through direct experience and investigative activities (Nur Rarastika et al., 2025). In addition, this approach has been proven to help students build connections between concepts and apply mathematical concepts in solving real-world problems.

A number of studies support this statement. Nailinda, Alim, and Sekarwinahyu (2025) found that STEM-based learning significantly improved the critical thinking skills of elementary school students. Another study by Yusuf, Ma'rufi, and Nurdin (2022) showed that STEM-based mathematics learning not only improved critical thinking but also student learning motivation at the secondary school level. These research results show that STEM integration is effective when applied at various levels of education.

In addition, a meta-analysis conducted by Rahmawati, Juandi, and Nurlaelah (2022) shows that the application of STEM has a large effect on students' mathematical creative thinking skills with a high effect size. These results reinforce the finding that STEM has a broad impact on the development of higher-order thinking skills, including analytical skills and creativity. Thus, STEM is not just a learning strategy, but a pedagogical paradigm that prioritizes authentic learning experiences.

From a theoretical perspective, the STEM approach is in line with the principles of constructivism, which emphasizes learning as an active process of constructing knowledge through experience and exploration. Ennis (1996) asserts that critical thinking skills develop when students are given the opportunity to analyze, evaluate, and make decisions based on evidence. The STEM approach facilitates this process through problem-solving, investigation, and engineering design activities.

However, implementing STEM is not always easy. Many schools face challenges such as teachers' limited knowledge in applying STEM, a lack of supporting media, and a lack of cross-disciplinary integration in schools. In addition, the STEM models used vary from project-based learning, problem-based learning, to engineering design process, and not all models show the same effectiveness in every learning context (Rahmawati & Juandi, 2022).

Apart from implementation challenges, there is also a research gap. Although many studies have examined the influence of STEM on general abilities such as creativity and motivation, research that specifically tests the effectiveness of STEM on mathematical critical thinking skills at the junior high school level is still limited (Toma, 2018). Meanwhile, critical thinking skills are very important at this level because students begin to learn more complex mathematical concepts that require deeper analysis.

The development of educational technology also reinforces the urgency of applying the STEM approach. The use of digital simulations, interactive devices, and STEM-based applications allows students to visualize abstract concepts and experiment with various variables without space and time limitations. Research by Mujib, Mardiyah, and Suherman (2022) shows that the use of STEM-based digital media can significantly improve students' mathematical literacy. This provides an opportunity for teachers to develop mathematics learning that is more interesting and relevant to the real world.

Considering the various research results, theoretical developments, and current educational needs, the application of the STEM approach in mathematics learning is highly relevant and urgent. Therefore, research on how STEM can improve students' critical thinking skills—especially at the junior high school level—needs to be conducted more deeply with a strong methodological approach. Through such research, a comprehensive understanding of the effectiveness of STEM, the factors supporting its success, and the practical implications for learning practices can be obtained.

Overall, research on the application of STEM in mathematics learning is expected to not only contribute to the development of theory but also serve as a basis for decision-making in educational practices in schools. Research findings can be used by teachers to design innovative, contextual, and high-level thinking skills-oriented learning. Thus, mathematics learning can become more meaningful and responsive to the needs of the 21st century (Hidayat, 2020; Nugraha, 2021; Rahmadhani et al., 2023).

METHOD

This study used a quasi-experimental method with a non-equivalent control group design, which compares two groups that are not randomly selected but have relatively comparable characteristics. In this study, one class was designated as the experimental class that received STEM-based learning, while the other class served as the control class that received conventional learning. This design was chosen because, in the school context, it was not possible to form new classes, so the study was conducted in existing classes. The research was conducted at a public junior high school in East Java for approximately three months, covering the stages of planning, implementation of learning, administration of pre-tests and post-tests, and data analysis. The research subjects consisted of 64 eighth-grade students selected using purposive sampling, which is the selection of two classes that are equivalent in terms of initial scores and previous academic profiles.

The independent variable in this study was the application of the STEM approach in mathematics learning, while the dependent variable was students' critical thinking skills. To measure these skills, a critical thinking test instrument was used, which was compiled based on Ennis' indicators, including the ability to analyze, make inferences, evaluate evidence, and draw conclusions. The test instrument consisted of essay questions and complex multiple-choice questions that required high-level thinking skills. In addition to the test, this study also included observation sheets of student and teacher activities to monitor student engagement in STEM learning, as well as a perception questionnaire to determine student responses to the learning model applied. The validity of the instruments was tested through content validity by involving mathematics education experts to ensure the suitability between the questions and critical thinking ability indicators, while the reliability of the instruments was obtained through limited trials on students outside the research sample.

The research procedure began with a pretest in both classes to determine students' initial abilities. Next, the experimental class received treatment in the form of STEM-based learning that integrated elements of science, technology, engineering, and mathematics through project activities and contextual problem solving. At the same time, the control class received conventional mathematics learning in accordance with the school curriculum. After the treatment ended, both classes were given a posttest to see the improvement in critical thinking skills. The pretest and posttest data were analyzed using the N-Gain test to see the relative improvement in critical thinking skills in each group and an independent t-test to determine the significant differences between the two groups. The results of the analysis were used to draw conclusions about the effectiveness of the STEM approach on the critical thinking skills of junior high school students.

RESULTS AND DISCUSSION

To determine the effectiveness of the STEM approach in improving critical thinking skills among junior high school students, this study conducted a comparative analysis between two groups, namely the experimental class and the control class. The experimental class received STEM-based mathematics instruction, while the control class continued to use the conventional learning model. Both classes were given critical thinking tests before and after the treatment.

The analysis of critical thinking skills improvement used N-Gain scores, which describe the extent of learning improvement after the treatment compared to the initial results. N-Gain scores were chosen because they provide an objective picture of the quality of improvement that occurred in both groups. In addition, this improvement indicator can also show the effectiveness of the learning model applied.

To provide a more structured understanding, the analysis results are presented in two separate tables. The first table contains the N-Gain results for the experimental class that used the STEM-based learning model. The second table contains the N-Gain results for the control class that used conventional learning. These two tables are expected to provide a clear picture of the difference in critical thinking skills improvement between the two groups.

Table 1. N-Gain Results for the Experimental Class (STEM Learning)

Aspect	Results
Learning Model	STEM (Science, Technology, Engineering, and Mathematics)
N-Gain Value	0.65
Improvement Category	Moderate–High
Description	There has been a significant increase in students' critical thinking skills.

Soure: processed by researcher, 2025

Table 2. N-Gain Results for the Control Class (Conventional Learning)

Aspect	Results
Learning Model	Conventional
N-Gain Value	0.34
Improvement Category	Moderate
Description	An increase occurred, but it was not significant.

Soure: processed by researcher, 2025

Based on the data in both tables, it can be seen that there is a clear difference between the improvement in critical thinking skills of students in both groups. In the experimental class that implemented STEM learning, an N-Gain value of 0.65 was obtained. This value falls into the medium-high category, indicating that the STEM approach has a positive and significant impact on improving students' critical thinking skills. This indicates that learning that involves the integration of science, technology, engineering, and mathematics is able to encourage students to think more analytically, reflectively, and systematically in solving problems.

In contrast, the control class, which learned through a conventional approach, only showed an increase with an N-Gain value of 0.34. This value falls into the moderate category, but the increase is not as strong as that seen in the experimental class. This indicates that conventional learning still has limitations in encouraging students' critical thinking skills because it tends to focus on procedures and exercises without providing context or real-life experiences that challenge students to think more deeply.

This significant difference in improvement can be explained by the role of STEM learning, which emphasizes hands-on experiences and contextual problem solving. When students are involved in projects or activities that connect mathematical concepts to real life, they are encouraged to observe, analyze, and evaluate information more critically. In addition, the STEM approach also encourages collaboration and communication skills, which are part of 21st-century competencies.

Overall, the data shows that STEM learning is more effective than conventional learning in improving the critical thinking skills of junior high school students. These findings reinforce the importance of integrating STEM into mathematics learning to create a more meaningful and interactive learning process that encourages students to think at a higher level.

Discussion

The results show that the application of the STEM approach in mathematics learning significantly improves students' critical thinking skills. This improvement can be seen from the N-Gain score of the experimental class, which was 0.65, placing it in the medium-high category. Meanwhile, the control class only achieved an N-Gain score of 0.34, which is in the medium category. This difference reflects the effectiveness of the STEM approach in creating a more meaningful and challenging learning experience for students. These findings are in line with the research by Rahmawati and Prasetyo (2020), which reported that STEM learning is able to encourage students to develop analytical and evaluative skills more consistently than traditional learning models.

The STEM approach encourages students to actively engage in the process of exploration, investigation, and problem solving. Through this model, students are required to integrate science, technology, engineering, and mathematics concepts in solving contextual problems. Project-based activities such as these provide opportunities for students to think critically by assessing evidence, analyzing data, and making decisions based on logical arguments. Nuraini et al. (2022) stated that students involved in STEM projects showed an increase in their ability to evaluate information and connect concepts more deeply than students who learned through lecture methods.

From a constructivist perspective, STEM learning provides a rich learning environment and places students at the center of learning. Through real-world problem-solving activities, students build new understanding from direct experience. This is reinforced by research by Dewi and Lestari (2021), which found that a project-based STEM approach increases student motivation, curiosity, and reflective skills, all of which are important components of critical thinking. In addition, Hasanah and Fitriani (2020) reported that the engineering design process in STEM learning helps students develop the ability to evaluate solutions and choose the most effective completion strategies.

In contrast, conventional learning applied in the control class appears to be unable to provide optimal stimulation for the development of critical thinking skills. Conventional learning usually focuses on delivering material and procedural exercises so that students tend to memorize steps without understanding the reasons behind them. Fauziah and Mahardika (2019) found that conventional learning methods do not provide enough space for students to evaluate ideas, present arguments, or develop alternative interpretations. This explains why the increase in critical thinking skills in the control class was lower.

In terms of learning engagement, the STEM approach is able to create a collaborative and interactive learning situation. Setyowati et al. (2023) emphasized that collaborative activities in STEM projects improve students' ability to ask critical questions, provide arguments, and assess the opinions of their peers. Social interaction in STEM learning also contributes greatly to the development of students' critical thinking skills through group discussions and joint problem solving. In addition, the use of technology such as mathematical simulations, analysis software, and digital learning media facilitates the exploration of concepts in a visual and interactive manner. According to Putra and Wulandari (2022), the use of technology in STEM learning helps students understand the relationships between mathematical concepts more clearly and deeply.

When linked to the demands of 21st-century education, the results of this study reinforce that the STEM approach is highly relevant for equipping students with higher-order thinking skills, including critical thinking, problem solving, creativity, and technological literacy. Larkin and Jorgensen (2019) in their international study stated that STEM integration contributes to students' readiness to face increasingly complex global technological developments. Therefore, the findings of this study emphasize the importance of teachers implementing STEM-based learning more broadly and structurally.

Overall, STEM learning has been proven to provide meaningful, contextual, and challenging learning experiences, thereby significantly improving students' critical thinking skills. This study implies that educators need to design interdisciplinary learning models that combine technology, projects, and problem solving to ensure that students have the competencies required in the modern era.

CONCLUSION

Based on the results of the study, it can be concluded that the application of the STEM approach in mathematics learning has a significant effect on improving students' critical thinking skills. This is reflected in the N-Gain scores of the experimental class, which were in the medium-high category, far above the control class, which only reached the medium category. STEM learning has been proven to create a more active, collaborative, and student-centered learning environment, enabling students to develop analytical, evaluative, and problem-solving skills through activities integrated with real-world contexts. Thus, the STEM approach is a relevant learning strategy to help students adapt to the demands of 21st-century competencies that emphasize higher-order thinking skills.

In line with these findings, it is recommended that teachers begin to systematically integrate STEM learning into mathematics learning by designing various project-based activities, using technology, and contextual problems that encourage critical thinking processes. Schools are also expected to provide support in the form of learning facilities, teacher training, and a learning environment that supports collaboration. For future researchers, this study can be developed by expanding the sample, using different materials, or adding other variables such as creativity, problem-solving skills, and technological literacy. In addition, curriculum developers need to consider a more comprehensive integration of the STEM approach as part of a strategy to modernize mathematics learning in schools.

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