JURNAL ABSIS
Jurnal Pendidikan Matematika dan Matematika
Vol. 8 No. 2, August 2025

EFFECTIVENESS OF THE STEM APPROACH IN IMPROVING STUDENTS' MATHEMATICAL CONCEPTUAL UNDERSTANDING ABILITY

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ABSTRACT This quasi-experimental study aims to examine the effectiveness of the STEM approach in enhancing students' understanding of mathematical concepts. The research was motivated by the low learning outcomes and limited student engagement in mathematics learning, which are presumed to result from the use of less effective instructional approaches. The STEM approach was chosen because it enables students to understand mathematical concepts contextually while fostering critical thinking, problem-solving, creativity, and collaboration skills. The sample consisted of 30 students from class VIII-1 and 31 students from class VIII-2, selected through purposive sampling. This study employed a *pretest–posttest control group design*, with quantitative data obtained from mathematical concept understanding tests. Data were analyzed using nonparametric statistical tests, including the Mann–Whitney U test and proportion test. The results of the Mann–Whitney U test at a 0.05 significance level showed that $z_{calculated} = 2.63 > z_{table} = 1.96$, indicating that H_0 was rejected and H_1 accepted. The findings revealed a significant difference in the improvement of conceptual understanding between students who received STEM-based instruction and those who experienced conventional learning. Moreover, more than 60% of students taught using the STEM approach achieved a good level of conceptual understanding. Therefore, it can be concluded that the STEM approach is effective in improving students' understanding of mathematical concepts.

Keywords: STEM approach, mathematical conceptual understanding, learning effectiveness

ABSTRAK Penelitian kuasi-eksperimental ini bertujuan untuk mengkaji efektivitas pendekatan STEM dalam meningkatkan pemahaman konsep matematis siswa. Latar belakang penelitian ini adalah rendahnya hasil belajar dan keterlibatan siswa dalam pembelajaran matematika, yang diduga disebabkan oleh penggunaan pendekatan pembelajaran yang kurang tepat. Pendekatan STEM dipilih karena diyakini mampu membantu siswa memahami konsep secara kontekstual sekaligus mengembangkan keterampilan berpikir kritis, pemecahan masalah, kreativitas, dan kolaborasi. Sampel penelitian terdiri atas 30 siswa kelas VIII-1 dan 31 siswa kelas VIII-2 yang dipilih melalui teknik purposive sampling. Penelitian ini menggunakan desain *pretest-posttest control group*, dengan data kuantitatif diperoleh melalui tes pemahaman konsep matematis. Analisis data dilakukan menggunakan uji statistik nonparametrik, yaitu uji Mann-Whitney U dan uji proporsi. Berdasarkan hasil uji Mann-Whitney U dengan taraf signifikansi 0,05 diperoleh nilai $z_{hitung} = 2{,}63 > z_{tabel} = 1{,}96$ sehingga H_0 ditolak dan H_1 diterima. Hasil penelitian menunjukkan adanya perbedaan yang signifikan dalam peningkatan pemahaman konsep matematis antara siswa yang mengikuti pembelajaran berbasis STEM dan siswa yang mengikuti pembelajaran konvensional. Selain itu, lebih dari 60% siswa yang belajar dengan pendekatan STEM menunjukkan tingkat pemahaman konsep yang baik. Dengan demikian, pendekatan STEM terbukti efektif dalam meningkatkan kemampuan pemahaman konsep matematis siswa.

Kata-kata kunci: pendekatan STEM, pemahaman konsep matematis, efektivitas pembelajaran

INTRODUCTION

Mathematics is a field of study that prioritizes logical reasoning in problem-solving processes (Nurfitriyanti, 2016). Mathematics education provides students with essential knowledge, attitudes, and skills (Kristanto & Santoso, 2020). In the 21st century, the mathematical competencies that should be cultivated include creativity, communication, critical thinking, problem-solving, and collaboration (Virmayanti et al., 2023; Arsanti et al., 2021; Ministry of Education and Culture of Indonesia, 2017). These competencies are closely linked to the use of technology (Mardhiyah et al., 2021), which, when integrated into mathematics learning, can help make abstract concepts more tangible and comprehensible (Rivai & Rahmat, 2023).

The significance of mathematics is emphasized in the learning objectives established by the Agency for Standards, Curriculum, and Educational Assessment (BSKAP) under the Ministry of Education, Culture, Research, and Technology in 2022, which include procedural skills and mathematical understanding, reasoning, problem-solving, representation, communication, connections, and disposition. Among these, conceptual understanding is recognized as the foundational competence that underpins the development of other mathematical abilities (Hidayat & Nuraeni, 2022).

Conceptual understanding serves as the foundation for developing various mathematical abilities, including reasoning, creativity, problem-solving, and communication (Sarumaha & Kurniasih, 2022). Students who possess strong conceptual understanding are better equipped to connect mathematical ideas, apply them in diverse contexts, and build more advanced skills (Fitriani et al., 2018).

However, the importance of conceptual understanding is not reflected in students' actual performance. According to the Programme for International Student Assessment (PISA), Indonesia in 2022 obtained an average score of 366, ranking 67th out of 81 participating countries, far below the international average of 472 (OECD, 2023). These results indicate that Indonesian students still face significant challenges in solving PISA tasks, which require analyzing, formulating, and communicating skills that depend heavily on strong conceptual understanding (Martalyna et al., 2018). Puspitasari and Ratu (2019) further highlight that low conceptual understanding is a key factor contributing to this difficulty, reinforcing the notion that a solid grasp of mathematical concepts is fundamental for success in PISA assessments (Ratu, 2019).

The low level of students' conceptual understanding in mathematics is also evident at State Junior High School 45 Bandar Lampung (SMP Negeri 45 Bandar Lampung). Results from a preliminary test consisting of two items assessing conceptual understanding showed that students experienced considerable difficulties in comprehending mathematical concepts. In addition, interviews with mathematics teachers indicated that limited student engagement during learning activities reduced their attention to the material, thereby hindering the development of their conceptual understanding (Hamzah, 2016).

The integration of Science, Technology, Engineering, and Mathematics (STEM) within real-life contexts serves as a powerful pedagogical approach to strengthen students' conceptual understanding. In particular, the adoption of STEM-based Project-Based Learning (PjBL) provides opportunities for students to actively engage in designing, exploring, and collaborating on projects that culminate in tangible products. Such learning experiences foster not only comprehension of mathematical concepts but also their meaningful application to authentic problem-solving situations. This approach moves beyond rote memorization, encouraging students to develop creativity, higher-order thinking skills, and problem-solving abilities through the integration of interdisciplinary knowledge (Kapila & Iskander, 2014; Ibnah & Rosidin, 2018; Erlinawari et al., 2019; Muthi'ik et al., 2018).

The effectiveness of the STEM approach in enhancing students' understanding of mathematical concepts has been supported by several empirical studies. Urpani and Kristayulita (2024) demonstrated that the integration of STEM significantly improves students' conceptual comprehension. Similarly, Ramadhani (2018) reported that students' learning enthusiasm and conceptual understanding increased through the implementation of STEM-based learning. In addition, Tipani et al. (2019) found that the application of the Project-Based Learning (PjBL) model can strengthen students' conceptual mastery and critical thinking skills. This is further reinforced by Sari et al. (2022), who highlighted that STEM-integrated PjBL contributes to the development of students' conceptual understanding. Consistent with these findings, Nabila and Azizah (2023) also revealed that students' mastery of mathematical concepts improved following the application of the PjBL approach.

Research on the effectiveness of improving students' understanding of mathematical concepts through the STEM approach is crucial, given the persistent challenges faced by students in this area. Preliminary findings indicate that many students struggle to grasp mathematical ideas, as reflected in test results and teacher interviews, which highlight the limited engagement of students during learning activities. This lack of active participation reduces students' attention to the material and hinders their ability to connect abstract concepts with real-life applications. The STEM approach is considered a potential solution, as it emphasizes contextual, meaningful, and experiential learning. Through STEM-based instruction, students are expected not only to enhance their conceptual understanding of mathematics but also to develop critical thinking, creativity, and problem-solving skills. Therefore, this study aims to examine the effectiveness of the STEM approach in fostering students' understanding of mathematical concepts.

METHODS

This study employed a quantitative approach with a quasi-experimental design. The population consisted of all 83 eighth-grade students of State Junior High School 45 Bandar Lampung (SMP Negeri 45 Bandar Lampung), distributed across three classes during the 2024–2025 academic year. Two classes were selected using purposive sampling, with Class VIII-1 assigned as the experimental group and Class VIII-2 as the control group. The experimental group was taught using the STEM approach, while the control group used the scientific approach. The study adopted a pretest–posttest control group design.

The quantitative data were obtained from the pretest and posttest scores of both groups, measuring students' understanding of mathematical concepts. The research instrument consisted of essay-type test items developed based on the learning objectives and indicators of conceptual understanding in mathematics.

The test instrument was examined for validity, reliability, item discrimination, and difficulty level before implementation. The validity test results indicated that all items were valid. The instrument was also tested on a group outside the study sample, showing that the items fell within the moderate to difficult categories, demonstrated good reliability, and had satisfactory discriminating power. Thus, the instrument was considered appropriate for use in this study.

The gain score was calculated by comparing the pretest and posttest results. A prerequisite test was then conducted, including a normality test using the Chi-Square test (Sugiyono, 2019). The results indicated that for the experimental group, H_0 was rejected, meaning that the gain score data did not come from a normally distributed population, while for the control group, H_0 was accepted, indicating that the gain score data were normally distributed.

Finally, hypothesis testing was carried out. Since the data were not normally distributed, a nonparametric Mann–Whitney U test was employed, followed by a proportion test to determine the effectiveness of the STEM approach in improving students' conceptual understanding in mathematics learning.

FINDING AND DISCUSSION

 https://doi.org/10.30606/absis.v8i2.3271

This section presents the results of data analysis and their interpretation to evaluate the effectiveness of the STEM approach in improving students' understanding of mathematical concepts. The analysis includes comparisons of pretest and posttest scores, gain scores, statistical test results, and a discussion of how STEM-based Project-Based Learning (PjBL) contributed to students' conceptual understanding during the learning process. Table 1 shows the initial data on students' understanding of mathematical concepts in the form of pretest scores obtained from classes using the STEM approach and classes using conventional learning.

Table 1. Pretest Results of Students' Mathematical Concept Understanding Ability

Class	Number of Students	Mean	Standard Deviation	Lowest Score (0–40)	Highest Score (0–40)
Experimental	30	8.4	5.73	0	22
Control	31	4.71	4.54	0	18

Based on Table 1, the average pretest score in the STEM-based learning class was higher than that in the conventional learning class. However, both classes still showed relatively low initial conceptual understanding scores before the learning process. Table 2 shows the final data on students' understanding of mathematical concepts in the form of posttest scores obtained from classes that used STEM-based learning and classes that used conventional learning.

Table 2. Posttest Results of Students' Mathematical Concept Understanding Ability

Class	Number of Students	Mean	Standard Deviation	Lowest Score (0–40)	Highest Score (0–40)
Experimental	30	30.20	7.84	4	39
Control	31	22.48	10.94	3	38

Table 2 shows that the mean posttest score in the STEM-based learning class was higher than in the conventional learning class. This finding indicates that the STEM approach had a positive effect on students' conceptual understanding compared to traditional methods. Recapitulation of data on the gain of students' mathematical concept understanding obtained from classes using the STEM approach and conventional learning is presented in Table 3.

Table 3. Gain Data of Students' Mathematical Concept Understanding Ability

Class	Number of Students	Mean	Standard Deviation	Lowest Score (0–40)	Highest Score (0–40)
Experimental	30	0.70	0.22	0.03	0.96
Control	31	0.52	0.27	0	0.94

According to Table 3, it is evident that the average improvement in students' conceptual understanding in STEM-based learning classes was greater than in classes using conventional learning. Both the lowest and highest scores were also higher in the class that used the STEM approach than in the conventional class.

Table 4 shows the achievement of indicators of students' conceptual understanding before and after the learning activities using the STEM approach and conventional learning.

Table 4. Achievement of Indicators of Students' Mathematical Concept Understanding Ability

Indicator	Experimental		Control	
	Start	End	Start	End
Restate a concept	30%	83%	28%	70%
Classify objects according to certain properties	27%	87%	3%	75%
Giving examples and non-examples	3%	68%	3%	48%
Presenting the concept	8%	53%	1%	33%
Develop necessary or sufficient conditions	0%	69%	0%	38%
Use, utilize, and select specific procedures or operations	33%	82%	15%	64%
Applying the concept	25%	74%	14%	54%
Mean	18%	74%	9%	55%

As shown in Table 4, both classes experienced improvement, but students in the STEM-based learning class achieved higher average scores for all indicators of conceptual understanding than those in the conventional class. Before learning, the average achievement of conceptual understanding indicators was 18% for the STEM-based class and 9% for the conventional class. After learning, the averages increased to 74% and 55%, respectively. This indicates that the increase in the STEM class (56%) was greater than in the conventional class (47%), showing that STEM-based learning produced better improvement in conceptual understanding.

The normality test used the Chi-Square Test with a significance level of $\alpha = 0.05$, where H_0 was accepted if $x^2count \leq x^2table$ with $x^2table = x^2(1-\alpha)(k-3)$. Based on the test results, the class using the STEM approach obtained $x^2count = 19.3568 > 7.81473$, which means H_0 was rejected; therefore, the data came from a population that was not normally distributed. Meanwhile, the improvement score data for the class using conventional learning was $x^2count = 5.2469 \leq 7.81473$, meaning H_0 was accepted, and the data came from a normally distributed population. Since the data were not normally distributed, the nonparametric Mann–Whitney U test was used.

https://doi.org/10.30606/absis.v8i2.3271

Based on the results of the Mann–Whitney U test with a significance level of 0.05, the value obtained was Zcount = 2.63 > Ztable = 1.96, so H_0 was rejected and H_1 accepted. These findings show a significant difference in the improvement of students' conceptual understanding between those who learned through the STEM approach and those who learned conventionally. Furthermore, the proportion test results showed Zcount = 3 and Ztable = 1.65; since Zcount > Ztable, H_0 was rejected. From these results, it can be concluded that more than 60% of students achieved a good level of mathematical conceptual understanding.

This indicates that the implementation of the STEM approach in learning improved students' conceptual understanding. Research by Urpani and Kristayulita (2024) also confirmed that the STEM approach is effective in enhancing students' ability to comprehend mathematical concepts. Hypothesis testing results indicated that students who participated in STEM-based learning experienced greater improvement in conceptual understanding than those in conventional learning. Moreover, more than 60% of students in the STEM group demonstrated good mastery of mathematical concepts. These results are consistent with Sari et al. (2022), who emphasized that the STEM Project-Based Learning approach significantly strengthens students' understanding of mathematical concepts.

In terms of overall performance in understanding mathematical concepts, the proportion of students in the STEM-based learning class was higher than in the conventional class. Among the seven observed indicators, the highest achievement was in the ability to classify objects based on specific attributes. Students engaged in STEM-based learning were able to identify similarities and differences between objects according to characteristics such as shape, relationships, and patterns. Consequently, they could apply their conceptual understanding effectively in solving problems. These findings are in line with Faoziah (2021), who stated that the ability of students to distinguish similarities and differences between objects based on mathematical properties reflects their problem-solving skills.

Through the initial stage of learning with the STEM Project-Based Learning approach, namely reflection, students were able to understand contextual problems in the fields of science, technology, engineering, and mathematics. In this stage, they comprehended STEM-related issues and the material studied with the help of project guidelines. The teacher provided stimuli related to SPLDV to encourage students to grasp key concepts and identify aspects that required further exploration. According to Wiratman et al. (2019) and Agustina et al. (2019), during the reflection stage, students can connect their learning to real-life experiences. Since each student has a unique perspective, they engage in discussions to exchange knowledge. Furthermore, Sukaesih et al. (2020) emphasized that students who understand contextual problems can restate what is known and what is asked in a problem. This indicates that the practice of restating problems serves as an important marker in enhancing students' comprehension of mathematical concepts.

The research phase constitutes the second stage of learning in the STEM Project-Based Learning model. At this stage, students' interest and enthusiasm in exploring concepts related to STEM and mathematics become apparent. The teacher provides guidance on how to collect relevant information and facilitates discussions to develop contextual understanding of how the project will be carried out. This aligns with Yamin et al. (2020), who emphasized that teachers play an essential role in encouraging and supporting students throughout the STEM-based project learning process to ensure that projects are completed effectively. Through investigation, observation, and data collection, students identify various properties of the given concept. In line with Micklo's theory, which states that individuals begin to classify objects once they recognize their characteristics (Astari & Chozin, 2019), students are able to categorize objects based on specific attributes.

The discovery phase represents the third stage of learning in the STEM Project-Based Learning model. During this phase, students encounter challenges in the process of experimentation and development, which are addressed through analysis, planning, and the application of numbers, symbols, and other mathematical representations. The teacher provides support by guiding students in formulating strategies to complete the assigned tasks. This aligns with Rahma (2024), who emphasized that in implementing STEM through the Project-Based Learning model, teachers play a crucial role in helping students understand the problem, design a plan, execute it, and draw conclusions.

The application phase is the fourth stage in the STEM Project-Based Learning model, where students implement the project plan based on the data collected (Sari, 2023). Since project time at school is limited, most activities are carried out outside school hours, giving students more opportunities to collaborate and complete the project optimally. At this stage, learning becomes more meaningful for understanding the topic being studied (Maharani, 2022; Kristiani et al., 2017). However, teachers must pay attention to supervision and classroom management during project activities to ensure a conducive learning environment.

Communication is the final learning phase in the STEM Project-Based Learning model. At this stage, students use presentation activities to share their project outcomes. Presentations are a crucial part of the learning process, as they improve communication skills and deepen understanding. This supports Mulyanti (2023), who stated that learning activities involving presentations and question-and-answer sessions are effective in enhancing student learning outcomes. Students are given the opportunity to reflect before responding to questions during these sessions (Shiddiq & Juleha, 2021). From the explanation, it is clear that using the STEM approach in learning has a greater potential to effectively enhance students' understanding of mathematical concepts.

CONCLUSIONS AND RECOMMENDATIONS

https://doi.org/10.30606/absis.v8i2.3271

The implementation of the STEM approach in mathematics learning proved to be effective in enhancing students' understanding of mathematical concepts in Grade VIII of SMP Negeri 45 Bandar Lampung during the 2024–2025 academic year. The results revealed that students who participated in STEM-based learning experienced significantly greater improvement in their conceptual understanding compared to those who followed conventional instruction. This finding was further supported by the fact that more than 60% of students in the STEM group achieved a good level of mathematical concept mastery. These results indicate that integrating STEM elements into learning provides students with meaningful, contextual, and inquiry-driven experiences that strengthen their conceptual comprehension in mathematics.

Based on these findings, it is recommended that teachers integrate STEM-based learning, particularly through project-based learning activities, to promote students' conceptual understanding and higher-order thinking skills. Future studies are encouraged to examine the long-term effects of STEM-based instruction across different mathematical topics and educational levels, as well as to explore how teacher facilitation, student collaboration, and assessment practices can further optimize learning outcomes in STEM-integrated mathematics education.

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