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STEM learning: innovative strategies to strengthen prospective teachers' science and mathematics concepts

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Abstract
Understanding the concepts of science and mathematics is a core competency that prospective elementary school teachers must have to teach integrated and relevant learning to the challenges of the 21st century. This study aims to analyze the influence of the STEM (Science, Technology, Engineering, and Mathematics) approach on the understanding of science and mathematics concepts of students of the basic education study program. This study uses a quasi-experimental quantitative design with a pretest-posttest one group design. The sample consisted of 26 students of the Madrasah Ibtidaiyah teacher education study program at the University of Muhammadiyah Magelang who were selected in total sampling. The research instrument is in the form of a test of understanding science and mathematics concepts. The results of the paired t-test analysis showed a significant increase in students' understanding of science and mathematics concepts after STEM-based learning ($p < 0.05$), showed an increase in the average concept comprehension score between the pretest (6.255) and posttest (6.619), as well as a decrease in score variability indicating an increase in the consistency of student understanding. These findings show that STEM approaches are effective in strengthening students' understanding of basic concepts, as well as encouraging integrated learning. This study recommends the implementation of STEM approaches in science and mathematics learning in teacher education.

Keywords
STEM approaches, Science concepts, Mathematics concepts, Elementary teacher education, Science education

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Introduction
One of the main challenges in Science, Technology, Engineering, and Mathematics (STEM) learning is the low mastery of basic concepts of Science and Mathematics among prospective teachers. Aspiring educators often face difficulties in associating theoretical concepts with practical applications [1], thus leading to a lack of deep understanding and relevance of the concept to real life. This is exacerbated by

traditional learning approaches that tend to focus on memorizing facts rather than applying concepts in a broader context.

In addition, the challenge of building problem-solving, critical thinking, and creativity among prospective teachers is a significant issue [2]. Prospective teachers need strategies that support cross-disciplinary exploration as well as allow them to integrate different fields within the STEM framework. Without innovative learning approaches, it is difficult for prospective teachers to prepare students for the challenges of the 21st century that demand higher STEM literacy.

Innovative STEM approaches can be a solution to strengthen the conceptual understanding of prospective teachers [3]. However, the implementation of this strategy is often plagued by a lack of effective understanding of STEM pedagogy among educators and educational institutions [4]. Therefore, it is necessary to develop innovative, relevant, and applicable STEM learning strategies to strengthen the science and mathematics concepts of prospective teachers, as well as improve their ability to integrate technology and creativity in learning.

To address the challenges in STEM learning, various approaches have been developed and implemented. Initially, STEM learning was introduced as an integrative method that combines science, technology, engineering, and mathematics in a single learning framework [5]. Early research emphasizes the importance of laboratory-based experiments to improve the understanding of scientific concepts of prospective teachers. However, this approach tends to be limited to the development of technical skills and does not fully integrate the collaborative and critical thinking aspects.

Over time, project-based learning (PBL) approaches began to be introduced as a major innovation. PBL allows prospective teachers to apply STEM concepts in real-world scenarios, encourage active learning, and improve problem-solving skills [6]. Additionally, the use of digital technologies, such as virtual simulations, interactive software, and web-based learning platforms, is growing in popularity to provide an immersive and contextual learning experience.

More recently, a Challenge-Based Learning (CBL) approach has been implemented to integrate creative and collaborative elements in STEM learning [7]. CBL encourages prospective teachers to identify real problems, design innovative solutions, and evaluate results systematically. In addition, STEM-based teacher training through workshops, seminars, and microteaching has also begun to be implemented to build relevant pedagogical and technical competencies [8].

Currently, research is starting to focus on personalizing STEM learning approaches, utilizing learning analytics to understand individual needs, and instilling technological literacy in every aspect of learning to strengthen the overall science and mathematics concepts of prospective teachers.

Although a lot of research has been done in STEM learning, some important aspects still go unnoticed. One of the main drawbacks is the lack of focus on developing adaptive pedagogical skills for prospective teachers. Many STEM approaches place more emphasis on technical mastery and application of science and math concepts, but fail to provide sufficient guidance on how to effectively teach those concepts to students with different learning styles.

In addition, previous research tended to pay less attention to the integration of local cultural elements and the context of daily life in STEM learning. In fact, the use of local context can increase the relevance of learning and help prospective teachers connect STEM concepts with real problems in society. This is very important to create a more meaningful and applicable learning experience.

Strengthening STEM learning aims to integrate science, technology, engineering, and mathematics concepts in applied learning, improve conceptual understanding, and build critical thinking, problem-solving, and creativity skills. This approach is important for prospective teachers to be able to teach these concepts effectively. STEM learning strategies involve innovations such as project-based learning, digital simulations, and collaborative activities that are relevant to real life. The integration of technology supports deeper learning and prepares aspiring teachers to face the challenges of the 21st century.

This study aims to evaluate the effectiveness of STEM-based learning in improving the understanding of science and mathematics concepts in prospective teachers, with a focus on improving students' critical thinking, problem-solving, and creativity skills. This study also examines the implementation of relevant STEM learning strategies in the context of teacher candidate education to improve STEM literacy and student pedagogical competence.

Method

This study uses a quantitative approach with a pretest-posttest one group design to evaluate the effectiveness of learning [9] STEM-based in improving students' understanding of science and mathematics concepts. This research will be carried out in October 2024. The research population includes students of the Madrasah Ibtidaiyah Teacher Education (PGMI) study program at the University of Muhammadiyah Magelang, with a sample of 26 students selected using the total sampling technique.

The research procedure consists of three main stages. The first stage is the pretest, where students are given an initial test to measure their understanding of science and mathematics concepts. The second stage is an intervention that is carried out in four STEM-based learning sessions. The third stage is the posttest, where students take the same test again to evaluate the improvement in understanding after the intervention.

In the first session of the intervention, students were introduced to the basic concepts of science and mathematics. Activities include explanations of the concepts of force (such as gravity and action-reaction), energy (potential and kinetic), and motion using interactive animated videos, and an introduction to basic mathematics such as flat shapes, types of flat shapes, and how to calculate the circumference and area. STEM activities in this session utilize PhET simulation applications to visualize the motion of objects and energy, helping students understand the basic principles concretely.

The second session focused on project-based science experiments. Students conduct simple experiments, such as measuring the relationship between gravitational force and kinetic energy using a ball and a tilted board. The results of the experiment were analyzed through group discussions to improve critical thinking skills. STEM activities in this session utilize spreadsheet applications to calculate and visualize experimental data, giving students hands-on experience in data processing.

The third session was directed at the application of mathematics in real life. Students are invited to solve project-based problems, such as calculating the area and circumference of the house plan. Group discussions were carried out to develop solutions and present the results of the calculations. The use of spreadsheet applications helps students calculate and visualize results more systematically, strengthening their skills in applying mathematical concepts in practical situations.

The fourth session integrates science, mathematics, and technology with a focus on environmental conservation. Students are asked to design simple projects, such as making solar panel models from simple materials or simulating the use of renewable energy. The project ended with a presentation of the results in front of the class. The STEM activities in this session involved simulation software to evaluate energy efficiency, helping students understand the benefits of green technology and its role in environmental conservation.

Overall, these intervention measures are designed to provide a holistic learning experience. Students not only learn science and math concepts but also how to apply them in real life, by combining technology and practical solutions to face the challenges of the modern world.

Results and Discussion

As part of efforts to understand the effectiveness of STEM-based learning, the analysis of outcomes and discussions is focused on improving students' understanding of science and mathematics concepts. This analysis includes a comparison of the average pretest and posttest scores, data distribution, and score variability presented in detail in Table 1. Through this table, a statistical description is presented that describes the change in average scores, standard deviations, and score ranges, which are the main indicators for evaluating the impact of STEM-based learning on student learning outcomes.

The results of this study show that STEM-based learning has a positive influence on improving students' understanding of science and mathematics concepts. Based on the results of descriptive statistical analysis, there was an increase in the average score from pretest to posttest. The average pretest score was 6.255, while the average posttest score increased to 6.619, with an increase of 0.364 points. This shows that there is an improvement in the performance of participants after receiving STEM-based learning interventions.

Table 1. Description of pretest and posttest statistics

Statistics	Pre-Test	Post-Test
Mean	6.255	6.619
Median (Middle value)	6.316	6.316
Standard Deviation (SD)	0.910	0.617
Range	3.158	2.105

The increase in the average score observed in the results of this descriptive analysis is further strengthened by data visualization through Figure 1 showing the histogram of pretest and posttest scores that illustrate changes in data distribution. The pretest histogram showed a less symmetrical distribution pattern, indicating considerable variation in performance among participants in the early stages. In contrast, the posttest histogram shows a more centralized distribution around a given score with a pattern that tends to be more symmetrical, reflecting an increase in the consistency of participants' scores after participating in STEM-based learning.

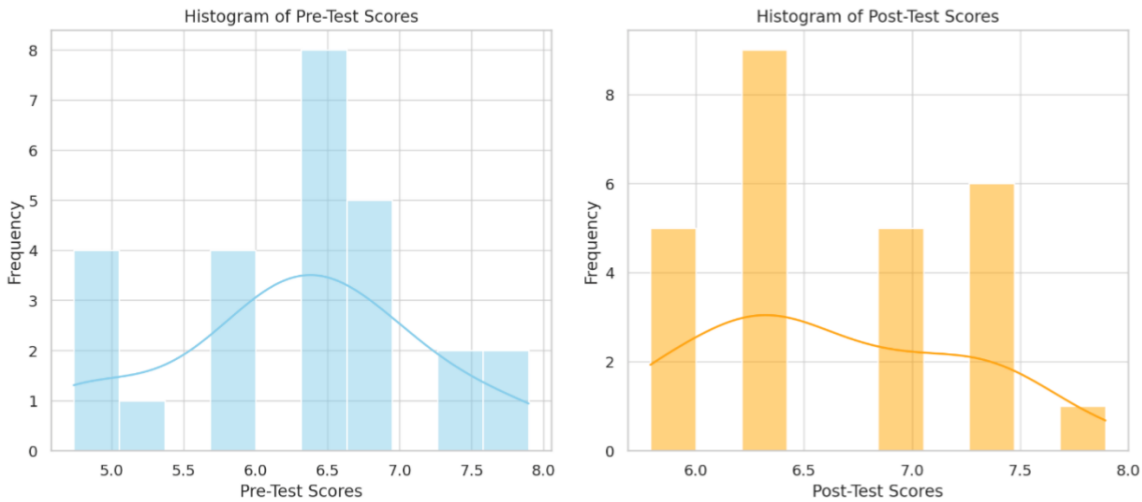

Figure 1. Pretest and posttest histograms

Standard deviation analysis showed that the score distribution in the posttest (0.617) was smaller than in the pretest (0.910). This means that the scores of participants on the posttest are more uniform, which reflects the increase in consistency of understanding between students. The value range in the pretest was 3.158, while in the posttest this range decreased to 2.105. This decrease in the range further confirms that participants show more uniform results after participating in STEM-based learning.

The relationship between descriptive statistical analysis and data visualization through boxplots further strengthens the conclusion that STEM-based learning has succeeded in increasing the consistency and uniformity of students' understanding of concepts.

Figure 2 shows the boxplot of the pretest and posttest results which confirms the findings of the research. In the pretest boxplot, it was seen that the distribution of scores was quite wide with the median being below the average, reflecting the high variability among participants before the intervention was carried out. In contrast, the posttest boxplot shows a narrower score distribution, with a higher median than the pretest, describing improved performance and consistency after STEM-based learning is implemented. The absence of extreme data (outliers) in both boxplots indicates that the entire data can be considered valid for analysis. This visualization provides a clear picture of the difference in score distribution before and after the intervention.

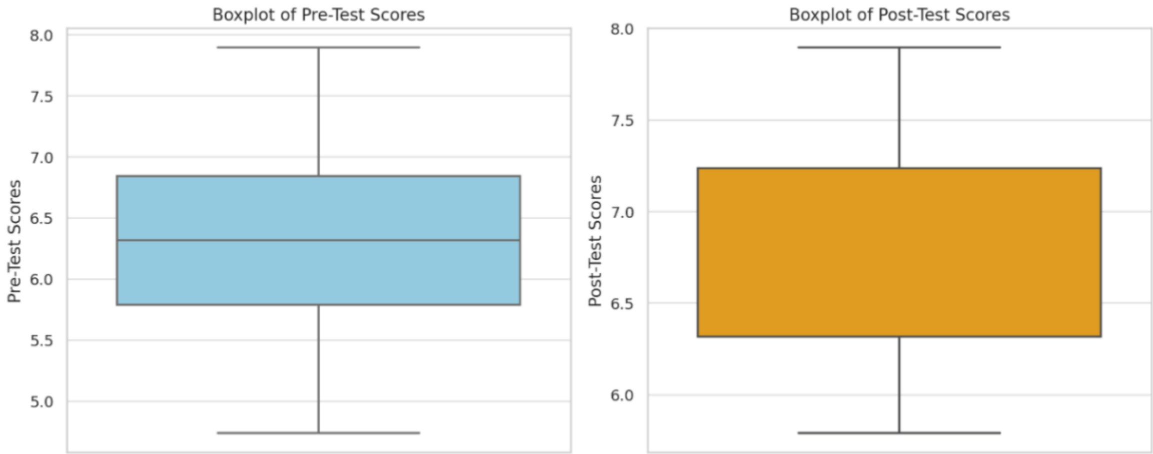

Figure 2. Boxplot pretest and posttest

Overall, the results of this study indicate that STEM-based learning not only improves the average understanding of students' concepts, but also improves the consistency and uniformity of scores among participants. This increase shows that STEM-based learning is effective in supporting a deeper understanding of science and mathematics concepts and helping students achieve more optimal learning outcomes [10].

STEM approaches have been proven to improve students' ability to relate science and mathematics concepts to real contexts through the integration of principles from various disciplines [11]. STEM-based learning helps students understand the application of theory to real-world problem-solving, strengthen critical and creative thinking skills, and improve understanding of the relationship between theory and application [6]. This provides a more well-rounded learning experience, where students understand how science, math, and technology are related in everyday life.

STEM-based experiments help students understand the practical application of science and mathematics concepts, relevant to learning in schools. Students can design and execute experiments that combine the principles of science and mathematics, giving them the skills to relate theories to phenomena experienced by school students. This approach prepares students to design contextual and engaging learning and encourages exploration and problem-solving.

The results of this study support the previous finding that STEM-based learning improves students' conceptual understanding and critical thinking skills [12]. By integrating science, technology, engineering, and mathematics, students not only gain a deeper understanding, but also be trained in critical and analytical thinking. STEM learning encourages students to solve problems effectively with higher-order thinking skills, which are in high demand in the professional world.

Conclusion

Based on the results of the research, STEM-based learning has proven to be effective in increasing the understanding of science and mathematics concepts in prospective teacher students. The increase in pretest and posttest scores, as well as the decrease in score variability, show that this learning not only deepens conceptual understanding, but also improves critical thinking skills and creativity. Integrative, STEM-based learning, using experiments, digital technology, and collaborative approaches, allows students to connect theory with practical applications. The implications of these findings are the importance of developing relevant STEM learning to prepare prospective teachers for the challenges of 21st century education. Further research can delve deeper into the influence of other factors, such as the role of facilitators and STEM curriculum adaptations, to improve learning effectiveness.

References

[1] I. Nugroho, I. Wilujeng, and P. Pujaningsih, "How Elementary Science Teachers' Understand Perform Science Process Skills and HOTS," in *5th Borobudur International Symposium on Humanities and Social Science 2023*, 2024, pp. 159–165.

[2] M. Matthee and M. Turpin, "Teaching critical thinking, problem solving, and design thinking: Preparing IS students for the future," *J. Inf. Syst. Educ.*, vol. 30, no. 4, pp. 242–252, 2019.

[3] P. M. Kurup, X. Li, G. Powell, and M. Brown, "Building future primary teachers' capacity in STEM: based on a platform of beliefs, understandings and intentions," *Int. J. STEM Educ.*, vol. 6, pp. 1–14, 2019.

[4] I. Imron, K. M. Khambali, A. S. Rifai, and I. Nugroho, "Development of A Soft Skills-Based Learning Model With A Behavioristic Approach," *J. Tarbiyatuna*, vol. 12, no. 2, pp. 108–120, 2021, doi: 10.31603/tarbiyatuna.v12i2.6018.

[5] G. H. Roehrig, E. A. Dare, J. A. Ellis, and E. Ring-Whalen, "Beyond the basics: A detailed conceptual framework of integrated STEM," *Discip. Interdiscip. Sci. Educ. Res.*, vol. 3, pp. 1–18, 2021.

[6] R. AlAli, "Enhancing 21st century skills through integrated STEM education using project-oriented problem-based learning," *Geo J. Tour. Geosites*, vol. 53, no. 2, pp. 421–430, 2024.

[7] A. A. A. Elzawahry and F. A. El Habashy, "The Effectiveness of Challenge-Based Learning in Developing Some Analytical Thinking Skills of STEM Students in the Faculty of Education." Zagazig University.

[8] M. A. Shahat and M. Al Amri, "Science teacher preparation in Oman: Strengths and shortcomings related to STEM education," in *Reforming Science Teacher Education Programs in the STEM Era: International and Comparative Perspectives*, Springer, 2023, pp. 161–179.

[9] G. Alessandri, A. Zuffianò, and E. Perinelli, "Evaluating intervention programs with a pretest-posttest design: A structural equation modeling approach," *Front. Psychol.*, vol. 8, p. 223, 2017.

[10] C. V McDonald, "STEM Education: A review of the contribution of the disciplines of science, technology, engineering and mathematics.," *Sci. Educ. Int.*, vol. 27, no. 4, pp. 530–569, 2016.

[11] T. R. Kelley and J. G. Knowles, "A conceptual framework for integrated STEM education," *Int. J. STEM Educ.*, vol. 3, no. 1, pp. 1–11, 2016.

[12] Y. Hacıoğlu and F. Gülhan, "The effects of STEM education on the students' critical thinking skills and STEM perceptions," *J. Educ. Sci. Environ. Heal.*, vol. 7, no. 2, pp. 139–155, 2021.