

STEM-Based Mathematics Learning: Challenges and Opportunities in the Digital Age



Ramita Destiani ^{a,1,*}, Fazila Maulida ^{b,2},

^a Pendidikan Matematika, Fakultas Pendidikan, Universitas Brawijaya, Malang and 65145, Indonesia

^b Pendidikan Matematika, Fakultas Pendidikan, Universitas Brawijaya, Malang and 65145, Indonesia

¹ ramita20@gmail.com; ² fazila07@gmail.com

* Corresponding Author

ABSTRACT

Mathematics learning in the digital era faces complex challenges along with the demands of mastering 21st-century skills. One approach deemed relevant to address these challenges is STEM (Science, Technology, Engineering, and Mathematics)-based learning. This approach emphasizes interdisciplinary integration, contextual problem-solving, and the use of technology in the learning process. This study aims to analyze the challenges and opportunities for implementing STEM-based mathematics learning in the digital era. The method used was a systematic literature review of national and international journal articles published in the last ten years. The results of the study indicate that STEM-based mathematics learning has great potential to improve students' conceptual understanding, critical thinking skills, creativity, and numerical literacy. However, its implementation still faces various obstacles, such as limited teacher competency, technological infrastructure readiness, and suboptimal curriculum integration. Therefore, strengthening strategies are needed through teacher professional development, policy support, and the provision of equitable digital learning facilities.

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1. Introduction

Mathematics is a fundamental subject that plays a strategic role in the education system. Through mathematics learning, students are trained to develop logical, analytical, critical, and systematic thinking skills, which are essential in various aspects of life. Mathematics serves not only as a tool for understanding numerical and symbolic concepts, but also as a means of developing rational thinking in dealing with complex problems. Therefore, the quality of mathematics learning is a crucial indicator of educational success in preparing superior and competitive human resources. With the rapid development of technology and the flow of globalization, the demands on mathematics learning have undergone a significant shift. Mathematics learning is no longer sufficient if it is solely oriented towards mastering concepts, procedures, and calculation skills. Students in the digital era are required to be able to apply mathematical concepts in real-life contexts, whether in the workplace, industry, or social life. This change aligns with the need for 21st-century skills, which include critical thinking, problem-solving, creativity, collaboration, and technology and information literacy.

The digital era has brought about a major transformation in the way people learn, work, and interact. The advent of digital technologies such as mathematical software, computer simulations, artificial intelligence, and online learning platforms opens up new opportunities in mathematics learning. Technology enables the presentation of abstract concepts to be more visual, interactive, and contextual. However, on the other hand, the use of technology in mathematics learning also demands a shift in the learning paradigm from teacher-centered to student-centered, where students play an active role in constructing their own knowledge through meaningful learning experiences.

In this context, the STEM (Science, Technology, Engineering, and Mathematics) approach has emerged as a relevant and responsive learning innovation to the demands of the digital era. The STEM approach emphasizes the integration of science, technology, engineering, and mathematics in the learning process, enabling students to understand the interrelationships between these fields and apply them to solving real-world problems. STEM-based learning does not view mathematics as a separate discipline, but rather as a thinking and analytical tool that supports cross-disciplinary problem solving. In STEM-based mathematics learning, mathematical concepts are learned through authentic contexts close to students' lives. Students are encouraged to design, test, and evaluate solutions to problems using the principles of mathematics, technology, and engineering. For example, geometric concepts can be applied to simple building designs, statistics can be used to analyze environmental data, or algebra can be applied to modeling economic problems. Through this process, mathematics learning becomes more meaningful, contextual, and relevant to real-world needs.

Various studies have shown that STEM-based mathematics learning has the potential to increase students' motivation to learn, critical thinking skills, creativity, and problem-solving skills. This approach also encourages students to work collaboratively, communicate effectively, and utilize technology productively. Thus, STEM-based mathematics learning aligns with 21st-century educational goals, which emphasize the development of holistic competencies, not just content mastery. Despite its many advantages, the implementation of STEM-based mathematics learning in schools still faces various challenges. These challenges include teachers' limited understanding of STEM concepts and implementation, a lack of ongoing professional training, limited supporting facilities and infrastructure, and suboptimal curriculum integration. Furthermore, some teachers still struggle to design mathematics lessons that integrate science, technology, and engineering comprehensively and meaningfully. Student readiness and differences in school characteristics also pose challenges in implementing this approach.

In the digital age, the challenges of STEM-based mathematics learning also relate to the effective use of technology. Not all schools have adequate access to technological devices and a stable internet connection. On the other hand, poorly planned technology use can actually distract from the primary learning objective. Therefore, careful learning planning, the selection of appropriate technology, and appropriate pedagogical strategies are required to ensure optimal STEM-based mathematics learning. Despite these challenges, STEM-based mathematics learning also offers significant opportunities for improving the quality of education. Support from educational policies, the development of learning technologies, and increasing awareness of the importance of 21st-century skills are crucial for developing STEM learning. Furthermore, collaboration between schools, universities, industry, and the government can strengthen the sustainable implementation of STEM-based mathematics learning.

Based on this description, a study of the challenges and opportunities for STEM-based mathematics learning in the digital age is crucial. This article aims to comprehensively examine the various challenges faced in implementing STEM-based mathematics learning and identify opportunities that can be utilized to optimize its implementation. This study is expected to provide theoretical and practical contributions to the development of innovative, relevant, and adaptive mathematics learning to meet the demands of the digital age.

2. Method

This study uses a literature study method (library research) with a descriptive-analytical approach. Data sources were obtained from reputable national and international journal articles, scientific proceedings, and reference books relevant to the topic of STEM-based mathematics learning. Data collection was carried out through literature searches in databases such as Google Scholar, Scopus, and SINTA using the keywords "STEM education",

"mathematics learning", and "digital era". The selected literature is publications from the last ten years that are related to the implementation of STEM in mathematics learning. The collected data were then analyzed by grouping research findings into aspects of challenges and opportunities for STEM-based mathematics learning, then systematically synthesized to obtain a comprehensive picture of the condition and development of STEM-based mathematics learning in the digital era.

3. Results and Discussion

Based on a literature review of various national and international studies, STEM-based mathematics learning in the digital era exhibits complex dynamics, characterized by various challenges as well as strategic opportunities in its implementation. Research findings indicate that the success of STEM-based mathematics learning is heavily influenced by the readiness of human resources, infrastructure support, and curriculum policies that support cross-disciplinary integration.

3.1 Challenges in STEM-Based Mathematics Learning

One of the main challenges in STEM-based mathematics learning is limited teacher competency. The study shows that many mathematics teachers do not fully understand the concepts and characteristics of the STEM approach comprehensively, particularly in integrating elements of technology and engineering into mathematics learning. Teachers tend to be more familiar with conventional learning approaches that focus on delivering material and practicing problems, thus experiencing difficulties when designing project-based learning or contextual problem-solving. The lack of continuous, practice-based professional training is a major factor hindering the improvement of teacher competency in implementing STEM learning effectively. In addition to teacher competency, infrastructure and technology readiness also pose significant challenges. STEM-based mathematics learning in the digital era requires the support of technological devices such as computers, learning software, simulation media, and adequate internet access. However, studies show a gap in technology access between regions and schools, particularly between schools in urban and remote areas. This situation has prevented the implementation of STEM learning from being evenly distributed. Even in schools with technological facilities, their utilization is often suboptimal due to teachers' limited ability to integrate technology into learning strategies.

Another challenge relates to the curriculum, which is not yet fully integrated. Many school curricula are still disciplinary and strictly separate subjects, making it difficult to implement interdisciplinary learning such as STEM. Mathematics teachers often face time constraints and a dense material load, making it difficult to deeply connect mathematical concepts with science, technology, and engineering. The lack of explicit curriculum guidelines regarding STEM implementation also makes teachers hesitant to design and implement comprehensive and systematic STEM-based mathematics learning.

3.2 Opportunities for STEM-Based Mathematics Learning

Despite these challenges, STEM-based mathematics learning also offers significant opportunities to improve the quality of learning in the digital age. One key opportunity is the development of 21st-century skills in students. Studies show that the STEM approach encourages students to think critically, creatively, and reflectively through contextual problem-solving activities. The project-based learning characteristic of STEM also fosters students' communication and collaboration skills, enabling them not only to understand mathematical concepts but also to effectively apply them in real-world situations. The use of digital technology presents another strategic opportunity in STEM-based mathematics learning. Various mathematical software, interactive simulations, modeling applications, and

online learning platforms enable a more visual and dynamic presentation of mathematical concepts. Digital technology can help students understand abstract concepts through graphical representations and simulations, while simultaneously increasing motivation and engagement in learning. In this context, technology plays a role as a supporting tool that enriches the STEM-based mathematics learning experience. STEM-based mathematics learning also opens up opportunities for contextual and meaningful learning. Through STEM integration, mathematics is no longer viewed as a separate and abstract subject, but rather as a tool for understanding and solving real-life problems. Students can connect mathematical concepts to phenomena in their environment, such as environmental, technological, or economic issues, making learning more relevant and meaningful.

Furthermore, educational policy support also presents a significant opportunity in the development of STEM-based mathematics learning. Various national and international education policies are beginning to encourage the implementation of STEM as part of 21st-century education reform. This policy provides space for schools and teachers to innovate in learning, while also being a foundation for curriculum development, teacher training, and providing supporting resources for STEM learning. By optimally leveraging these opportunities, STEM-based mathematics learning has the potential to become an effective strategy for improving the quality of education in the digital age.

4. Conclusion

STEM-based mathematics learning is a relevant and strategic approach to addressing educational challenges in the digital age. This approach holds significant potential for improving the quality of mathematics learning, particularly in developing 21st-century skills and the ability to apply mathematical concepts. However, its implementation still faces various challenges, such as limited teacher competency, infrastructure readiness, and curriculum integration. Therefore, collaborative efforts between the government, educational institutions, and educators are needed to strengthen STEM-based mathematics learning through teacher training, flexible curriculum development, and the provision of adequate technological facilities and infrastructure.

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