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Implementing STEM-Based Mathematics Learning in Indonesian High Schools: Teachers' Understanding, Challenges, and Supporting Factors

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Abstract: STEM is a learning approach that can enhance students' mathematical skills by linking mathematics with science, technology, and engineering, thereby increasing students' motivation. This study analyzed teachers' understanding and the challenges they face in implementing STEM-based mathematics instruction. A phenomenology-informed qualitative study explored the experiences of 12 mathematics teachers across six provinces in Indonesia: West Java, Central Java, East Java, Yogyakarta, West Sumatra, and West Nusa Tenggara. Data were collected through online interviews and analyzed using the Bogdan & Biklen technique, including data reduction, axial coding, theme determination, and conclusion and interpretation. The results indicate that teachers view STEM-based mathematics as a means to connect subjects, develop critical 21st-century skills, and apply knowledge in real-life contexts. They implement STEM through project-based, interdisciplinary lessons that increase student engagement, despite challenges such as time constraints, curriculum demands, and differences in student readiness. Effective STEM instruction relies on professional development, school support, and sufficient resources to enable teachers to integrate STEM concepts confidently into mathematics teaching. These findings highlight the importance of providing structured guidance, adequate teaching materials, and policy support to enhance teachers' capacity to deliver STEM-based mathematics effectively, bridging theory and practice for meaningful student learning.

Keywords: STEM-Based Math Learning, Teacher understanding, Challenges, Supporting factors

Introduction

Mathematics learning in schools is expected to equip students with problem-solving skills that enable them to respond effectively to real-world situations. Accordingly, mathematics education extends beyond procedural mastery to the development of students' mathematical thinking, reasoning, and intellectual growth. As Risnanosanti and Ristontowi (2019) noted, the goals of mathematics learning go beyond applying mathematical knowledge to problem solving and include cultivating broader competencies that support cognitive development. In response, governments and educational institutions have increasingly promoted STEM-based mathematics learning as an approach to enhance students' mathematical competence. STEM-based learning is commonly understood as a student-centred, constructivist approach that emphasises interdisciplinary integration and authentic problem solving, encouraging students to draw on knowledge from multiple disciplines to address real-life challenges (Metpattarahiran, 2021; Nhung & Hanh, 2021). STEM, an acronym for Science, Technology, Engineering, and Mathematics (Bybee, 2013), represents an integrated framework in which these disciplines function as interconnected domains supporting meaningful learning experiences (Chuchalin & Zamyatin, 2021; Lai & Chu, 2017). Within this framework, science supports conceptual understanding and the application of scientific principles (Palacios, 2022), technology enhances engagement through digital tools in learning activities (Douglas et al., 2025), engineering fosters systematic design and analytical thinking (Horváth & Farkas, 2025), and mathematics serves as a core tool for modelling, reasoning, and problem solving through critical and creative thinking.

Furthermore, STEM education has been widely recognised as essential for promoting innovation, preparing a skilled workforce, and addressing complex societal challenges. John et al. (2016) define STEM learning as an approach that integrates the four disciplines to solve authentic problems, while Kennedy and Odell (2014) describe each component as contributing distinct yet complementary knowledge and skills. Science focuses on understanding nature and its principles, technology involves the effective use of tools to support human activities, engineering emphasises procedural design and problem-solving skills, and mathematics concerns logical reasoning and quantitative relationships. The integration of these disciplines is believed to foster more meaningful and transferable learning experiences for students. As noted by Jolly (2017), although STEM is a practical acronym representing traditional school subjects, its structure does not imply a hierarchy but rather highlights the importance of integration. Similarly, Honey et al. (2014) emphasise that engineering serves as a bridge that applies scientific, mathematical, and technological concepts to real-world problem solving.

Ideally, mathematics instruction in the classroom should be student-oriented and actively engage learners in constructing knowledge. Project-based learning is often proposed as an effective instructional strategy to support such engagement, as it allows students to work collaboratively or independently to explore problems and develop solutions. Within STEM-based mathematics learning, projects are designed to integrate science, technology, engineering, and mathematics while also fostering students' global competence. Through these projects, students are expected to become more active learners and to develop higher-order thinking skills. In this learning environment, the teacher plays a crucial role as a facilitator who guides, supports, and directs students throughout the learning process. However, teachers' capacity to design and implement STEM-oriented mathematics instruction remains a critical issue. For instance, Risdiyanti et al. (2024) highlight that inadequate teacher capacity, particularly in integrating mathematical literacy with interdisciplinary and community-based contexts, can limit the effectiveness of STEM learning environments.

A growing body of research has reported positive outcomes associated with the implementation of STEM in mathematics and science education. Wissman & Leontyev (2024) found that incorporating fact-based and hands-on practices in STEM classrooms can improve student achievement and retention. Dikilitaş (2015) emphasised the importance of engaging, hands-on activities as a key strategy for effective STEM implementation. Studies conducted in the Indonesian context have also demonstrated the potential benefits of STEM-based learning, such as improved problem-solving skills and learning achievement through STEM-oriented trigonometry learning tools (Arivina & Jailani, 2020), as well as increased motivation and independent learning through technology-supported STEM approaches (Argianti & Andayani, 2021). These findings suggest that STEM-based mathematics learning holds promise for enhancing student outcomes when implemented effectively.

Despite these positive findings, numerous studies have documented significant challenges in the implementation of STEM, particularly from the perspective of teachers. Hai et al. (2023) reported that teachers in Vietnam experienced multiple challenges in STEM implementation, with limited understanding of STEM concepts and practices emerging as the most critical issue. Similarly, Weng (2023) identified insufficient teacher knowledge and lack of external support as major barriers to STEM implementation. Nguyen & Tran (2024) further noted that professional competence and unfamiliarity with STEM programme methodologies pose substantial challenges for educators. In the context of mathematics education, Diana et al. (2021) found that teachers faced difficulties related to low STEM understanding, inadequate facilities, and limited instructional time. Other studies have also shown that teachers struggle with classroom management, curriculum development, and addressing practical constraints due to their limited understanding of STEM (Aslam et al., 2023). In Indonesia, recent curriculum reforms have increasingly promoted STEM-based learning to foster higher-order thinking, problem solving, and interdisciplinary skills. Nevertheless, implementing these expectations in secondary mathematics classrooms remains challenging, as teachers must integrate STEM principles while managing curriculum demands, assessment requirements, and diverse student needs, often with limited professional development and instructional support. Collectively, these studies indicate that teachers' insufficient understanding of STEM concepts and applications constitutes a central obstacle to the effective implementation of STEM-based mathematics learning.

Given these challenges, there is a clear need for research that examines STEM implementation from the perspective of teachers, particularly in contexts where empirical evidence remains limited. In Indonesia, studies that comprehensively explore mathematics teachers' understanding of STEM, their experiences in implementing STEM-based instruction, and the factors that support or hinder their practices are still scarce. To achieve the research objectives, the researcher employed a phenomenological approach. Phenomenology was chosen because it aims to describe how a phenomenon is experienced and understood, rather than testing the initial hypothesis. The phenomenological approach was chosen because the research wanted to reveal how teachers genuinely understand STEM-based mathematics learning in depth, not just measuring knowledge in numbers or scores.

Addressing this gap, the present study aims to investigate Indonesian high school mathematics teachers' understanding of STEM-based mathematics learning, their implementation practices and the challenges they experienced, and the supporting factors that facilitate STEM integration in classrooms. Adopting a phenomenological framework, this study seeks to provide in-depth insights into teachers' lived experiences. The findings are expected to contribute to the existing literature on STEM education, inform teacher professional development, and offer practical implications for curriculum designers and policymakers. By foregrounding teachers' perspectives, this study contributes theoretically to the STEM education literature by offering a nuanced understanding of how STEM-based mathematics learning is conceptualised and enacted at the classroom level. Practically, the findings are expected to inform teacher professional development programs, support schools in designing feasible STEM-oriented instruction, and assist policymakers in developing more context-sensitive strategies for STEM integration in secondary mathematics education.

Therefore, this study is focused on finding: (1) Indonesian mathematics teachers' understanding of STEM-based mathematics learning; (2) Indonesian mathematics teachers' practices in implementing STEM-based mathematics learning; and (3) what factors support Indonesian mathematics teachers in implementing STEM-based mathematics learning.

Methodology

This study uses a qualitative research design informed by the main principles of phenomenology to explore the life experiences of mathematics teachers with STEM-based mathematics learning, by adopting a phenomenological approach. While phenomenology traditionally seeks to uncover the universal essence of experience through procedures such as epoché and phenomenological reduction (Moustakas, 1994), this study selectively applied phenomenological principles to allow methodological flexibility and contextual sensitivity, focusing on shared meanings across participants' accounts as commonly practiced in educational research (Creswell & Poth, 2016). The study was conducted in the natural context of Indonesian high school mathematics education and involved teachers from six provinces: Central Java, Yogyakarta, West Sumatra, West Nusa Tenggara, West Java, and East Java, where STEM-based learning has increasingly been promoted as an instructional innovation.

In phenomenological research, participants must have directly experienced the phenomenon being studied to enable the identification of its essential meanings (Moustakas, 1994). Accordingly, this study involved twelve high school mathematics teachers (see Table 1) with firsthand experience in implementing STEM-based mathematics learning. Participants were selected through purposive sampling based on predefined criteria, including a minimum of two years of teaching experience at the high school level and willingness to participate in an online interview. Recruitment was conducted voluntarily via a Google Form distributed through WhatsApp, and two teachers from each province were selected from the eligible respondents to form a homogeneous sample aligned with Moustakas's emphasis on shared lived experience in phenomenological analysis.

Table 1. Participant Demographic Characteristics

Category	Subcategory	n	%
Gender	Male	3	25
	Female	9	75
Age	25–30	4	33.3
	31–40	3	25
	41–50	2	16.7
Educational Background	Bachelor's degree (S1)	8	66.7
	Master's degree (S2)	4	33.3
Teaching Experience (years)	1–5	5	41.7
	6–10	3	25
	11–15	1	8.3
	16–25	3	25
N		12	100

Each participant was coded with the initial letter representing the province (e.g., JG = Central Java, YG = Yogyakarta, NTB = West Nusa Tenggara, JB = West Java, SM = West Sumatra, JT = East Java) and the number indicating the teacher's sequence (e.g., 1 = first teacher, 2 = second teacher), ensuring anonymity and traceability of responses.

Data were collected through in-depth semi-structured interviews, which are central to phenomenological research because they allow participants to articulate their experiences in detail (Yuksel-Arslan et al., 2016). The interviews were conducted online via Zoom, lasted approximately 45–60 minutes, and were scheduled according to participants' availability, with questions focusing on teachers' understanding of STEM, their experiences in implementing STEM-based mathematics instruction, the challenges they encountered, the strategies they employed, and the forms of support they perceived as necessary. To enhance credibility, interviews were conducted in two stages to allow clarification and temporal triangulation of responses. In this qualitative study, the researcher served as the primary research instrument and was directly involved in all stages of data collection and analysis, including designing the interview guide, conducting the interviews, and interpreting the data, while maintaining reflexive awareness to minimize potential bias and ensure that interpretations remained grounded in participants' lived experiences.

Data were analysed following Bogdan and Biklen's (2007) qualitative framework within a phenomenological approach. Interviews guided by nine questions exploring teachers' understanding, implementation, challenges, and needs in STEM-based mathematics learning were transcribed verbatim and systematically organized.

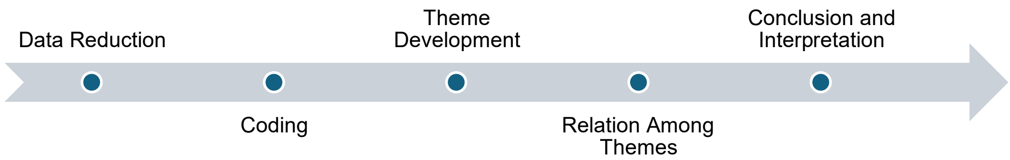

Figure 1. Data Analysis Mode

Analysis involved four iterative stages: data reduction, axial coding, theme determination, and inference and interpretation. Meaningful statements were identified, coded, and grouped into sub-themes, which were then synthesized into central themes representing shared experiences. All data obtained from questionnaires and interviews with mathematics teachers were tabulated, after which data reduction was carried out. The results of the data reduction were then used to code the data based on the categorization of data according to the research questions. The results of the axial coding data were then categorized based on sub-themes, and from each sub-theme, the researcher determined the main theme that represents the overall research findings. The relationships between components, sub-themes, and main themes are then presented in the form of a table. The validity of qualitative research refers to the results of interviews that have been conducted. Therefore, the researcher must carefully ensure the validity of the interview results.

First, the researcher must be directly involved in the interview process. Second, the researcher coded the interview results through temporal triangulation, identified sub-themes, and finally drew conclusions.

Results and Discussion

This section presents the findings of the study, highlighting the experiences and perspectives of the participants related to the main focus of the research. The results are organized into three subsections, each corresponding to one of the research questions in sequential order. This structure allows a clear presentation of emerging patterns, themes, and insights, which are further detailed in the following subsections.

Teachers' Understanding of STEM-Based Mathematics Learning

To provide a detailed overview of teachers' understanding of STEM-based mathematics learning, Table 2 presents a thematic representation of their perceptions and conceptualisations of STEM. The table summarizes key central themes, sub-themes, representative quotes, and analytical insights, highlighting how teachers integrate interdisciplinary knowledge, 21st-century skills, and real-world applications to support effective, engaging, and meaningful mathematics instruction.

Table 2. Thematic Representation of Teachers' Understanding of STEM-Based Mathematics Learning

Central Theme	Sub-theme	Excerpt	Analytical Insight
STEM Integration	Interdisciplinary Approach	"*Interrelated disciplines often taught through an interdisciplinary approach to develop critical thinking, collaboration, and real-world problem-solving skills*" (JG1)	Teachers perceive STEM as an interdisciplinary approach that connects mathematics with other subjects to support collaborative and holistic learning.
	Subject Collaboration	"*An educational approach that integrates or collaborates Science, Technology, Engineering, and Mathematics*." (NTB1)	
	Conceptual Understanding	"*Mathematics learning connected to technology, as an acronym for Science, Technology, Engineering, and Mathematics*" (YG1)	
21st Century Skills	Critical Thinking	"*An approach that combines disciplines of Science, Technology, Engineering, and Mathematics to foster critical and creative thinking for solving real-world problems*" (YG2)	Teachers view STEM-based learning as a practical strategy for developing problem-solving, innovation, and collaborative skills across multiple disciplines.
	Creativity and Innovation	"*Developing 21st-century skills such as critical thinking, creativity, collaboration, and problem-solving, while preparing students to face real-world challenges and meet the demands of a technology-driven economy*" (SM2)	
	Collaboration	"*Collaboration of Science, Technology, and Mathematics, applying mathematics in real-*	

Central Theme	Sub-theme	Excerpt	Analytical Insight
		world contexts through science and technological support." (JB2)	
Real-World Application	Contextual Learning	"*Mathematics learning becomes more contextual as it is applied to real-world situations*" (JT1)	Teachers view STEM-based learning as a strategy for meaningful, context-driven instruction that develops students' problem-solving abilities through technology-supported applications.
	Problem-Solving	"*An approach that combines disciplines of Science, Technology, Engineering, and Mathematics to foster critical and creative thinking for solving real-world problems*" (JM2)	
	Technology Application	"*Collaboration of Science, Technology, and Mathematics, applying mathematics in real-world contexts through science and technological support*." (JB2)	

The analysis of teachers' perceptions of STEM-based mathematics learning reveals three central themes: STEM Integration, 21st Century Skills, and Real-World Application. Teachers perceive STEM Integration primarily as an interdisciplinary approach that connects mathematics with other subjects, fostering holistic and collaborative learning. They emphasize subject collaboration, where the integration of Science, Technology, Engineering, and Mathematics enables students to approach problems from multiple perspectives, and conceptual understanding, recognizing that linking mathematics with technological and scientific concepts helps students grasp the broader STEM framework. This indicates that teachers recognize STEM not merely as separate content areas but as a holistic educational approach integrating knowledge, skills, and application (Dare et al., 2021; Faikhamta, 2020).

Building on this, teachers highlight that STEM-based learning develops critical thinking, creativity and innovation, and collaboration, making it an effective strategy to enhance problem-solving skills, promote innovative thinking, and facilitate teamwork, while preparing students to face real-world challenges and meet the demands of a technology-driven economy. Awareness of 21st-century skills including critical thinking, problem-solving, collaboration, and creativity (4Cs) demonstrates a pedagogical orientation toward preparing students for global challenges (Karahan et al., 2015). The use of project-based, interdisciplinary teaching practices shows teachers' efforts to operationalise their understanding into concrete classroom activities. Nevertheless, observed challenges such as limited instructional time and varied student readiness indicate that theoretical knowledge alone is insufficient, highlighting the need for structured planning and scaffolding to ensure successful STEM integration (Nghitoolwa & Ntandokamenzi, 2025; Wilkerson et al., 2023). Furthermore, professional development, school support, and adequate resources reinforce teachers' competence, enabling them to overcome constraints and continuously improve STEM-based mathematics teaching (Geng et al., 2019; Stevenson et al., 2025). The findings suggest that teachers' understanding of STEM as a multi-disciplinary and skill-oriented approach aligns with the theoretical principles of STEM education emphasising integration and meaningful application.

In terms of Real-World Application, teachers stress the importance of contextual learning, where mathematics instruction is applied meaningfully in real-life scenarios. STEM learning supports problem-solving by enabling students to explore practical solutions, and technology applications allow them to implement mathematical concepts effectively through scientific and technological tools. Effective STEM implementation relies on thorough professional development, strong school support, and adequate resources, which empower teachers to confidently integrate STEM concepts into mathematics instruction (Geng et al., 2019; Stevenson et al., 2025). In terms of teaching practices, teachers implement STEM through project-based, interdisciplinary lessons, which enhance student engagement. However, challenges such as time limits, curriculum constraints, and variations in student readiness affect the optimal execution of STEM-based activities (Mayes & Rittschof, 2021; Selimi et al., 2025). In conclusion, teachers view STEM-based mathematics learning as an interdisciplinary, skills-oriented, and context-driven approach that integrates multiple subjects, fosters critical 21st-century skills, and enables students to apply knowledge meaningfully in real-world contexts.

Teaching Practices and Challenges in STEM-Based Mathematics

To examine how teachers' understanding of STEM-based mathematics is enacted in the classroom, Table 3 presents teaching practices and implementation challenges. The table summarizes key central themes, sub-themes, representative quotes, and analytical insights, highlighting how teachers apply STEM principles through project-based, interdisciplinary, and technology-supported activities while managing practical constraints such as time, student readiness, and curriculum limitations.

Table 3. Thematic Representation of Teaching Practices and Implementation Challenges in STEM-Based Mathematics

Central Theme	Sub-theme	Excerpt	Analytical Insight
STEM Implementation	Partial Implementation	*"It is very necessary and highly suitable, though rarely practiced, because mathematics often ends up as mere calculation. When combined with science, it becomes something new."* (JB1)	Teachers implement STEM in mathematics through project-based and interdisciplinary approaches, using real-life contexts and technology to support student learning.
	Project-Based Learning	*"Learning becomes context- and project-based. For example, calculating the volume of a rectangular prism is transformed into calculating the capacity of a water tank to be designed for a village."* (NTB2)	
	Integration with Other Subjects	*"I have applied mathematics learning based on other disciplines. For instance, in probability, I connected it to students' interest in running. For technology integration, I asked students to create digital posters."* (JT1)	

Central Theme	Sub-theme	Excerpt	Analytical Insight
Student Engagement	Motivation and Interest	*"It is highly positive because it makes mathematics learning more real and relatable to everyday life, making learning enjoyable and meaningful."* (SM2)	Teachers observe that integrating real-world and practical activities in STEM-based mathematics enhances student engagement, motivation, and collaborative learning.
	Hands-on Activities	*"I have tried this with 3D material, such as constructing frameworks of cubes and rectangular prisms. Students created frameworks using their own measurements, aiming to understand structure, surface area, and volume."* (JB2)	
Challenges in STEM	Time Constraints	*"So far, the challenge has been limited time when applying calculations to object height and preparing the required media."* (JT2)	Teachers perceive practical challenges in STEM-based mathematics, including time pressure, students' lack of readiness, and limited curriculum integration.
	Student Readiness	*"A challenge is that students are not precise or careful when solving problems in the worksheets."* (JB1)	
	Curriculum Limitations	*"Conceptually, STEM is not yet well understood, so lesson design is not optimal, though efforts have been made to integrate technology."* (SM1)	

The analysis of teaching practices in STEM-based mathematics highlights three central themes: STEM Implementation, Student Engagement, and Challenges in STEM. Teachers implement STEM primarily through partial implementation, applying project-based and interdisciplinary approaches that connect mathematics with real-life contexts and technology. These findings are consistent with prior research emphasizing the importance of a holistic understanding of STEM for effective classroom implementation (Dare et al., 2021; Faikhamta, 2020; Talib et al., 2025). They use project-based learning, such as transforming volume calculations of a cuboid into designing a water tank for a village, and emphasize integration with other subjects, incorporating students' interests and technological tools like digital posters. Previous studies also show that project-based, interdisciplinary lessons enhance students' engagement and conceptual understanding, aligning with the current results (Lee et al., 2019; Selimi et al., 2025). These practices reflect teachers' efforts to make mathematics instruction more meaningful, applied, and engaging for students.

Regarding Student Engagement, teachers observe that STEM-based mathematics significantly enhances motivation and interest, as lessons become more relatable and enjoyable, while hands-on activities allow students to construct three-dimensional models, calculate dimensions, and apply mathematical concepts practically. However, teachers also face practical challenges in STEM, including time constraints, student readiness, and curriculum limitations, which can restrict the full integration of STEM approaches. The observed emphasis on professional development, school support, and adequate resources confirms prior research highlighting their critical role in enabling teachers to integrate STEM concepts confidently (Geng et al., 2019; Hrynevych et al., 2022; Karpudewan et al., 2023;

Stevenson et al., 2025). However, some findings differ from contexts with stronger institutional support, where implementation was smoother. In the Indonesian context, time constraints, curriculum limitations, and varied student readiness continue to influence the effectiveness of STEM integration. In conclusion, teachers strive to implement STEM-based mathematics through project-based, interdisciplinary, and context-driven strategies that actively engage students, yet practical constraints such as limited time, students' preparedness, and curriculum gaps remain significant obstacles.

Factors Supporting STEM-Based Mathematics Implementation

To understand how teachers can successfully implement STEM-based mathematics despite practical challenges, Table 4 presents the key factors that support their practice. The table summarizes central themes, sub-themes, representative quotes, and analytical insights, highlighting how professional development, school support, and access to resources empower teachers to apply STEM principles effectively in mathematics classrooms.

Table 4. Thematic Representation of Factors Supporting STEM-Based Mathematics Implementation

Central Theme	Sub-theme	Excerpt	Analytical Insight
Teacher Training	Intensive Training	"*In-depth training is necessary, but it must include hands-on practice and supportive facilities for STEM learning. School schedules should also allow adequate time*." (NTB1)	Teachers perceive professional development programs, including training and workshops, as essential for deepening STEM knowledge and guiding classroom implementation.
	Workshop & Webinar	"*There is training available; currently, all schools are conducting STEM training with coding, organized by the education office*." (JB1)	
School Support	Institutional Support	"*Support is provided by both the school and the education office for implementing STEM-based learning*" (SM2)	Teachers perceive school and institutional support, teacher collaboration, and sufficient facilities as critical factors for successful STEM implementation.
	Teacher Collaboration	"*Necessary facilities include the ability to collaborate with teachers from different disciplines at school, support from the school for projects to be conducted in the lab, and implementation guidebooks*." (JT2)	
	School Facilities	"*Intensive training by experts is needed for teachers who are willing to participate. Flexible time is required, facilities should support product creation, and ideally, the school provides all necessary resources*" (JB1)	
Resource Availability	Learning Materials	"*There are many STEM training programs that enable us to implement STEM in teaching, including examples such as instructional videos, modules, and STEM applications in mathematics*." (JB2)	Teachers perceive videos, modules, and technological tools as critical resources for applying STEM concepts in mathematics classrooms.
	Technological Tools	"*Professional training and development are needed to integrate STEM approaches into mathematics teaching, along with adequate classroom internet access and technological devices*." (SM2)	

The analysis of factors supporting STEM-based mathematics implementation highlights three central themes: Teacher Training, School Support, and Resource Availability. Teachers emphasize the importance of intensive training, where professional development programs include hands-on practice and flexible time allocation to deepen STEM knowledge and guide classroom implementation. They also highlight workshops and webinars, noting that formal training opportunities, such as coding workshops organized by educational authorities, help teachers acquire practical skills for STEM integration. Partial implementation of STEM-based mathematics learning may be explained by teacher- and student-related factors. Teachers' limited understanding of STEM concepts, insufficient planning time, and difficulties implementing interdisciplinary activities impede optimal execution. Students' passivity, unfamiliarity with technological tools, and perceptions of increased workload further constrain engagement (Oztay et al., 2022; Shekhar et al., 2020). Moreover, variations in school resources, infrastructure, and institutional support affect the consistency and quality of STEM delivery. These professional development activities provide teachers with the knowledge and confidence necessary to apply STEM effectively in mathematics instruction.

In addition, School Support plays a crucial role, encompassing institutional support, teacher collaboration, and adequate school facilities. Teachers perceive that collaboration with colleagues from different disciplines and access to laboratory space, guidance materials, and administrative support are essential for successful implementation. Likewise, Resource Availability, including learning materials such as videos, modules, and technological tools, is considered vital for applying STEM concepts in the classroom. In conclusion, the successful implementation of STEM-based mathematics relies on comprehensive professional development, strong school support, and sufficient resources, which together enable teachers to integrate STEM effectively into their teaching practices. Even when teachers are motivated and knowledgeable, the lack of concrete examples, structured guidance, and technological tools may prevent the full translation of STEM theory into practice. Nonetheless, professional development, hands-on training, and self-directed learning enable teachers to overcome many of these obstacles, highlighting that limitations are not solely due to teacher competence but also systemic and contextual factors (Geng et al., 2019; Hrynevych et al., 2022; Karpudewan et al., 2023; Stevenson et al., 2025). These explanations provide a plausible account for why STEM-based mathematics learning, although conceptually understood, has not yet reached its full potential in Indonesian classrooms.

Conclusion

This study revealed that Indonesian mathematics teachers perceive STEM-based mathematics as an integrative approach that connects multiple disciplines, fosters essential 21st-century skills, and allows students to apply mathematical knowledge in meaningful, real-world contexts. In practice, teachers implement STEM through project-based and interdisciplinary lessons that enhance student engagement, although they face challenges such as limited instructional time, strict curriculum requirements, and varied student readiness. Successful STEM integration is supported by comprehensive professional development, strong school backing, and sufficient teaching resources, which collectively empower teachers to apply STEM concepts effectively. These findings contribute to a theoretical and practical understanding of STEM education. Theoretically, teachers consider STEM integration primarily as an interdisciplinary approach that connects mathematics with other subjects, encouraging holistic and collaborative learning. Practically, these findings highlight the relationship between teacher cognition, pedagogical strategies, and contextual support, and suggest practical steps for policymakers and school administrators to improve the effectiveness of STEM teaching.

Despite its insights, The only stated limitation is the geographical scope of the study. Additional limitations that must be acknowledged include: (1) the self-reporting bias inherent in the interview data, (2) significant gender imbalances in the sample (75% women), and (3) the risk that two teachers per province may not represent the various school contexts in each region. Future research could investigate how teachers' STEM self-efficacy influences students' critical thinking and problem-solving skills, examine the effects of integrating digital learning tools and simulations on interdisciplinary STEM learning, or explore STEM-based mathematics implementation in vocational, rural, and under-resourced schools. Further studies could also compare novice and experienced teachers' approaches, evaluate longitudinal student outcomes from STEM instruction, and analyze how curriculum flexibility and assessment strategies impact STEM teaching effectiveness. Practical advice for teachers should pay close attention to time management strategies during the learning process so that learning goals can be achieved. For the school, it can provide a cross-disciplinary laboratory so that teachers can collaborate to combine mathematics learning with physics lessons or other subjects. As for the Government, it can revise the curriculum for STEM flexibility so that the implementation can run well.

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