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Elementary teachers' understanding of STEM integration: A study in the Indonesia – Malaysia border area

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Abstract

Science, Technology, Engineering, and Mathematics (STEM) education is vital in preparing students to face future challenges by fostering critical thinking and problem-solving skills. However, in border areas such as Indonesia and Malaysia, the implementation of STEM education remains underexplored. This study uses a quantitative descriptive-comparative design to analyze school teachers' understanding of STEM implementation. It involves 44 teachers from the Indonesia-Malaysia border area in Bengkayang Regency, West Kalimantan, Indonesia. Data were collected using a Likert-scale questionnaire and analyzed through descriptive statistics and an independent t-test to assess and compare teachers' levels of understanding. The findings indicated moderate scores for STEM knowledge (3.84), implementation practices (3.71), and school support (3.66), while challenges scored low (2.98). In terms of teaching experience, there was no significant difference between teachers with less than 10 years and those with more than 10 years of experience concerning their understanding of STEM implementation in elementary schools. This is attributed to the limited availability of training programs that could enhance teachers' knowledge regarding STEM education.

Keywords: border area; elementary school; teachers' understanding; STEM

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Introduction

Science, Technology, Engineering, and Mathematics (STEM) is crucial in establishing a foundation for critical thinking and problem-solving skills from an early age. Mathematics helps students understand abstract concepts through real-world applications, such as geometry in building design or numbers in fuel calculations (Agusningtyas et al., 2024; Chen et al., 2024; Hebebci & Usta, 2022). This practical approach enhances understanding and motivates students by highlighting the relevance of what they learn (Sapounidis et al., 2024).

As a global education priority, especially at the elementary level, STEM promotes science and technology mastery and 21st-century skills like creativity and collaboration (Tunc & Bagceci, 2020). Teachers' understanding is crucial for effective implementation. This study explores how teachers apply STEM in practice using the TPACK framework, which assesses how content, pedagogy, and technology are integrated to support effective teaching and learning.

The STEM approach integrates science, technology, engineering, and mathematics to create a holistic, interdisciplinary learning experience that helps students connect concepts across fields (Tunc & Bagceci, 2020). It emphasizes hands-on, project-based activities that foster critical thinking, creativity, and real-world problem-solving. By combining theory with practical application, STEM prepares students for future challenges and careers in science and technology while cultivating collaboration, communication, and other essential 21st-century skills. Ultimately, STEM education enhances scientific literacy and equips students to thrive in a globalized world.

Furthermore, implementing STEM in mathematics education at the elementary level encourages students to work collaboratively and develop communication skills (Schreiter et al., 2024). When presented with STEM-based projects—such as designing building patterns using geometric concepts or calculating probabilities in simple games—students learn to discuss, share ideas, and tackle challenges together (Hu et al., 2024; Küçükaydın et al., 2024). It aligns with the demands of 21st-century education, which emphasizes higher-order thinking skills and teamwork. Thus, STEM education not only enhances students' mathematical understanding but also shapes them into individuals prepared to face global challenges in the future (Permanasari et al., 2021; Pertiwi et al., 2024; Sulaeman & Efwinda, 2021).

Effective STEM implementation in elementary schools requires strategic planning, particularly in designing learning activities that integrate science, technology, engineering, and mathematics (Zinth et al., 2020). Project-based learning is a widely used strategy that engages students in solving real-world problems collaboratively, fostering theoretical understanding and practical application (Pangestu et al., 2024; Tunc & Bagceci, 2020; Hasanah, 2020)). Successful case studies show that STEM can be integrated through community-based projects, where students, teachers, and local stakeholders work together on initiatives such as addressing environmental issues. These practices illustrate the potential of STEM to enhance student engagement and promote meaningful learning. Equally important is the evaluation of STEM learning outcomes. Teachers must implement formative and summative assessments and collect student feedback to measure instruction effectiveness and identify areas for improvement.

Continuous evaluation supports the refinement of teaching strategies and ensures that STEM education contributes to students' academic growth and development of essential 21st-century skills.

Teachers play a central role in implementing STEM education to develop students' critical thinking, creativity, collaboration, and problem-solving skills. As facilitators, teachers must design project-based and exploratory learning experiences that allow students to discover concepts through hands-on experiences actively (Sreylak et al., 2022). For instance, in mathematics learning, teachers can engage students in solving real-world problems, such as designing mini bridges using geometric principles or calculating material requirements for simple projects (Purnasari et al., 2023; Saputro et al., 2024). Through this approach, students grasp academic concepts and develop critical thinking skills by analyzing problems, discovering innovative solutions, and evaluating their work outcomes.

Additionally, teachers serve as motivators who encourage students' creativity and collaboration in facing STEM challenges. By assigning team-based tasks, such as designing energy-efficient devices or creating data-driven ecosystem models, teachers create a learning environment that encourages students to work together, share ideas, and develop innovative solutions (Christensen & Osgood, 2024). Teachers must also guide students in utilizing technology and learning tools to explore various possibilities in problem-solving. With the right strategies, STEM education enhances students' academic understanding and equips them with essential 21st-century skills to tackle future challenges.

Teachers' understanding of STEM significantly influences the success of STEM curriculum implementation in the classroom. Educators with a firm grasp of STEM concepts tend to be more confident in teaching these subjects to their students (Nugraha et al., 2024; Yang & Ball, 2024). Conversely, teachers with a limited understanding of STEM may feel hesitant and uncertain about integrating this approach into their teaching. Therefore, it is crucial to explore how teachers comprehend STEM and the challenges and opportunities they face in their teaching practices. Several factors that affect teachers' understanding of STEM include educational background, professional training, and teaching experience (Nguyen & Tran, 2024; Wang & Xiao, 2022). Teachers who have received specialized training in STEM education have a better understanding and are more capable of implementing this approach in the classroom. Furthermore, teaching experience plays a vital role; educators who have previously taught using STEM approaches may feel more comfortable and confident integrating these concepts into their learning (Waters, 2022).

Although many teachers recognize the importance of STEM education, they often encounter challenges in understanding and applying it. These challenges include resource limitations, lack of school support, and varying understandings of the STEM concept (Liu, 2020). A packed curriculum and pressure to meet academic standards can also hinder teachers from effectively integrating STEM into their teaching. Therefore, identifying and addressing these challenges is crucial for teachers to teach STEM more effectively and maximally.

Elementary school teachers face various challenges in understanding and implementing STEM education, particularly because this approach requires a deep understanding of interdisciplinary concepts and holistically integrating science, technology, engineering, and mathematics. One of the main challenges is the limited training and resources available to teachers (Agusningtyas et al., 2024; Purnasari et al., 2023; Yllana-Prieto et al., 2025). Many teachers have not received specialized training in STEM education, making it challenging to design activities that align with the curriculum and meet students' needs. Furthermore, inadequate school facilities—such as laboratories, technological tools, and interactive learning materials—pose barriers to implementing project-based learning, a key characteristic of STEM education. Additionally, teachers' readiness to transition from conventional teaching methods to exploratory and problem-solving approaches presents challenges. STEM education requires teachers to act as facilitators, encouraging students to think critically and creatively rather than merely delivering content directly (Agusningtyas et al., 2024; Gunawan et al., 2023; Pertiwi et al., 2024). Students' varying abilities in understanding STEM concepts also add to the challenges for teachers, who must adjust their teaching strategies to ensure all students can engage actively. Therefore, support from the government, schools, and the educational community—through training, mentoring, and the provision of adequate resources—becomes a key factor in helping teachers effectively implement STEM education in elementary schools.

Despite the increasing global and national emphasis on STEM, research exploring its implementation in rural or border regions of Indonesia—such as schools in the Indonesia–Malaysia border area—remains limited. Most existing studies focus on urban or resource-rich settings, leaving a knowledge gap regarding how STEM is understood and applied in geographically isolated or underserved communities. This study seeks to address that gap by focusing on elementary school teachers' comprehension and implementation of STEM education in the Indonesia–Malaysia border region.

This study examines the extent of elementary school teachers' understanding of STEM implementation in teaching, including how they integrate science, technology, engineering, and mathematics concepts into their instructional practices. Additionally, this research seeks to analyze whether there is a correlation between teachers' years of experience and their level of STEM comprehension. Specifically, the study will compare STEM understanding between teachers with extensive teaching experience and those relatively new to the profession. By analyzing differences in understanding based on teaching experience, this study can provide insights into the factors influencing teachers' mastery of STEM concepts and how teaching experience contributes to their comprehension and application of STEM in the classroom. The findings of this research can serve as a foundation for developing more targeted professional development programs to enhance elementary school teachers' understanding and application of STEM education.

Methods

This study employed a quantitative approach with a descriptive-comparative research design to analyze the level of teachers' understanding of STEM implementation in elementary school learning (Li, 2024). Data collection was conducted through the distribution of questionnaires to 44 elementary school teachers selected using purposive sampling, with the selection criteria including teaching at public elementary schools in rural areas along the Indonesia – Malaysia border. The sample included schools with varying sizes and available teaching resources to ensure representation of diverse teaching contexts. The comparative variable in this study is teaching experience.

The research instrument consists of a closed-ended questionnaire based on a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), measuring three main aspects: teachers' understanding of STEM concepts, implementation strategies in teaching, and challenges encountered in applying STEM in the classroom, each of which consists of 8 specific indicators. To ensure the quality of the data, the questionnaire underwent a validity and reliability test. Construct validity was assessed through expert judgment to confirm that the instrument accurately reflects the concepts being measured. Reliability was assessed using Cronbach's alpha to determine the internal consistency of the questionnaire items. A Cronbach's alpha coefficient of 0.70 is generally considered acceptable, with higher values indicating stronger internal consistency.

The collected data were analyzed using descriptive statistics to illustrate the distribution and trends in teachers' understanding of STEM implementation. Furthermore, to examine differences in understanding based on teaching experience, this study employs an independent t-test, which is appropriate for comparing two independent data groups. The cutoff point of 10 and 10 years of experience was chosen based on prior literature, which often uses 10 years as a threshold for distinguishing novice from experienced teachers in professional development studies (Brody & Hadar, 2015; Lőrincz & Greba, 2022; Prodan & Constantin, 2024).This statistical analysis aims to determine the significance of differences in STEM comprehension between teachers with varying years of experience, providing insights into the impact of teaching experience on teachers' readiness to implement STEM-based learning.

Results

Teachers' fundamental knowledge of STEM

The research findings indicate that elementary school teachers' understanding of STEM in the Indonesia-Malaysia border region is relatively good, with an overall average score of 3.841. It suggests that teachers have a high level of awareness regarding the importance of STEM in education. However, despite their strong conceptual understanding, challenges remain in implementation, particularly regarding teaching strategies and access to resources that support STEM integration. The measured indicators reveal that teachers feel confident in explaining STEM's definition, objectives, and benefits. However, there is still room for improvement in the practical application of STEM in the classroom. The distribution of teachers' fundamental knowledge of STEM is presented in Figure 1.

Figure 1 presents the distribution of questionnaire responses regarding teachers' fundamental knowledge of STEM. This aspect consists of eight indicators, with the following average scores: "I understand the basic definition of STEM" (3.84), "I can explain the primary objectives of implementing STEM in elementary education" (3.86), "I am aware of the benefits of STEM education for students' skill development" (4.00), "I understand how STEM enhances students' critical thinking skills" (4.02), "I know how to integrate various disciplines in STEM learning" (3.61), "I have knowledge of effective teaching strategies for STEM" (3.68), "I can provide examples of STEM activities suitable for elementary students" (3.82), "I am familiar with various resources that support STEM implementation" (3.89).

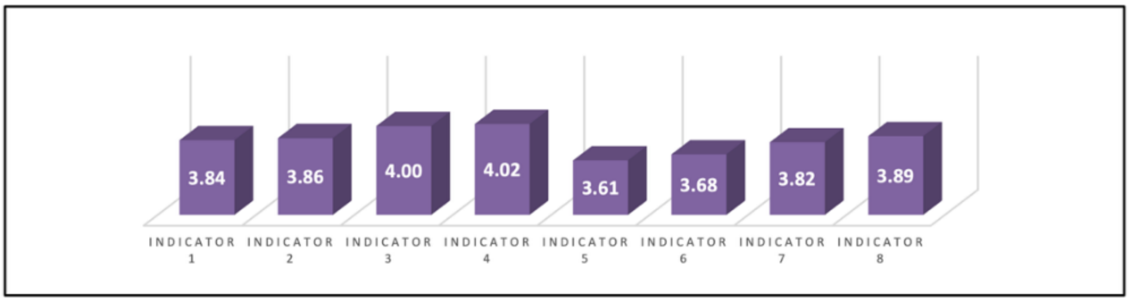

Figure 1. Teachers' fundamental knowledge of STEM

Frequency and methods of STEM implementation in elementary school learning

The questionnaire results on the frequency of STEM implementation in elementary school learning indicate an overall average score of 3.71. It reflects that teachers understand the importance of implementing STEM in education. However, variations in scores across specific indicators suggest differences in how teachers apply STEM principles in the classroom. The most prominent indicator highlights the use of technological tools or devices, whereas encouraging students to engage in independent experimentation and research remains an area for improvement. The distribution of average scores for this aspect is presented in Figure 2.

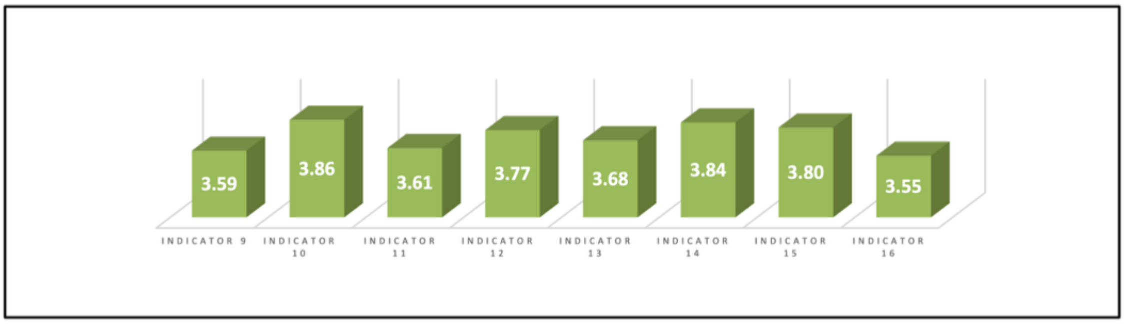

Figure 2. Frequency and methods of STEM implementation in elementary school learning

Based on Figure 2, the distribution of scores for each indicator is as follows: Indicator 9, "I regularly incorporate STEM activities into lesson planning," scored 3.59; Indicator 10, "I use technological tools or devices to support STEM activities in class" scored 3.86; Indicator 11, "I periodically integrate STEM learning with other subjects" scored 3.61; Indicator 12, "I engage students in practical STEM projects or experiments" scored 3.77; Indicator 13, "I modify the curriculum to include more STEM elements" scored 3.68; Indicator 14, "I assign STEM-based tasks that encourage student creativity and innovation" scored 3.84; Indicator 15, "I use a project-based approach for STEM learning" scored 3.80; Indicator 16, "I encourage students to conduct independent experiments and research in STEM" scored 3.55.

Challenges in implementing STEM

The survey results regarding the challenges in implementing STEM indicate an overall average score of 2.98. This score reflects that teachers face various obstacles in integrating the STEM approach into their classrooms. While several challenges were identified, the severity of these difficulties varies, with certain indicators highlighting more significant obstacles than others. This underscores the need for greater attention to factors influencing the successful implementation of STEM in elementary schools. The distribution of scores related to the challenges in STEM implementation is presented in Figure 3.

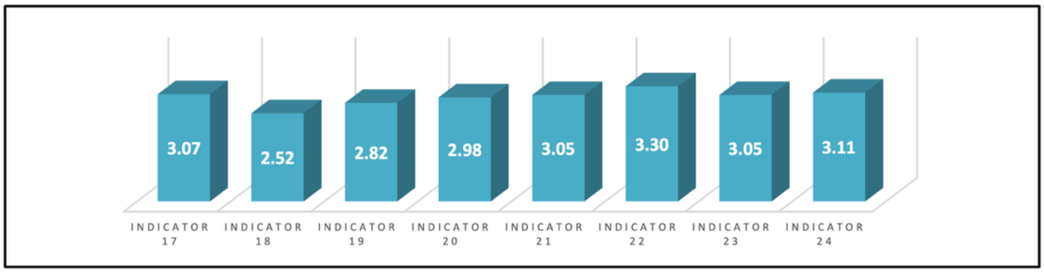

Figure 3. Challenges in implementing STEM

The Challenges in STEM Implementation aspect also comprises eight indicators. Figure 3 illustrates the distribution of teachers' understanding regarding these challenges. The scores for each indicator are as follows: 1) Indicator 17, "I struggle to find relevant teaching materials for STEM" (3.07); 2) Indicator 18, "I feel that I do not receive sufficient support from the school administration for STEM implementation" (2.52); 3) Indicator 19, "I face difficulties in accessing the necessary technological tools for STEM" (2.82); 4) Indicator 20, "I do not feel adequately trained to implement STEM effectively" (2.98); 5) Indicator 21, "I have difficulty managing time for STEM activities outside the curriculum" (3.05); 6) Indicator 22, "I struggle to adapt STEM activities to students with different learning abilities" (3.30); 7) Indicator 23, "I feel constrained by the lack of resources or supporting facilities in my school" (3.05); dan 8) Indicator 24, "I find it challenging to address differences in students' skill levels in STEM activities" (3.11).

Availability of resources and support from the school

The results of the questionnaire regarding the availability of resources and support from the school indicate an overall average score of 3.66. This score suggests that, in general, teachers perceive their schools as providing adequate support for the implementation of STEM in teaching and learning. However, there are variations in scores across specific indicators, indicating that while support is present, certain aspects still require improvement to better facilitate the implementation of STEM in the classroom. The distribution of achievement in the aspect of resource availability and school support is presented in Figure 4.

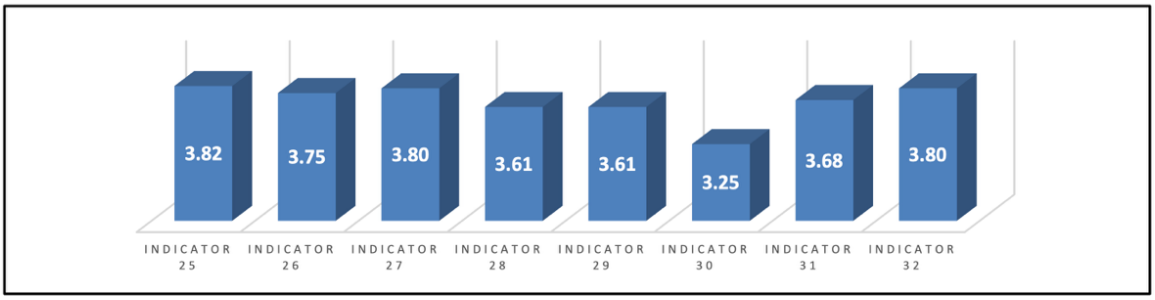

Figure 4. Availability of resources and support from the school

Figure 4 illustrates teachers' comprehension of the availability of resources and support from the school in relation to the implementation of STEM education in primary schools. Indicator 25, "The school provides adequate resources to support STEM activities," received a score of 3.82. Indicator 26, "The school offers training or workshops related to STEM for teachers," scored 3.75. Indicator 27, "I receive the necessary technical support to carry out STEM activities," obtained a score of 3.80. Indicator 28, "The school has adequate facilities for practical STEM activities in the classroom," scored 3.61. Indicator 29, "The school provides constructive feedback on STEM implementation," also scored 3.61. Indicator 30, "The school provides incentives or recognition for teachers' efforts in implementing STEM," received the lowest score of 3.25. Indicator 31, "The school provides teaching materials or instructional aids relevant to STEM activities," scored 3.68. Indicator 32, "There is collaboration between the school and the community to support and expand STEM activities," scored 3.80. Based on the Teaching Experience of Primary School Teachers in the Indonesia-Malaysia Border Region, the results of the analysis using an independent t-test are presented in Figure 5 below.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p			Lower	Upper
Skor	Equal variances assumed	3.059	.088	.655	42	.258	.516	.09636	.14712	-.20053	.39326
	Equal variances not assumed			.655	32.958	.259	.517	.09636	.14712	-.20297	.39569

Figure 5. Independent samples test

Figure 5 presents a Sig. (2-tailed) value of 0.516, which is greater than 0.05. This indicates that there is no significant difference between the teaching experience of primary school teachers in the Indonesia-Malaysia border region and their understanding of STEM implementation.

Discussion

In the context of education in border regions, teachers' fundamental understanding of STEM is crucial in its successful implementation. Studies indicate that teachers strongly grasp the basic definition of STEM and its objectives in elementary education. It is reflected in an average score of 3.84, demonstrating a consensus on the significance of STEM in education. These findings align with the research of Permanasari et al. (2021), which emphasizes that although teachers' conceptual understanding of STEM is relatively strong, its practical application in teaching still requires improvement. The benefits of STEM education, such as fostering critical thinking skills and integrating multiple disciplines, are a central focus of this study. With an average score of 4.02, teachers exhibit a high level of awareness regarding the role of STEM in equipping students with 21st-century skills. Research by Sulaeman and Efwinda (2021) suggests that STEM-based learning enhances student engagement and prepares them for future challenges, particularly in border areas where resource limitations are prevalent. This finding is also consistent with the study by Bharti (2022), which indicates that elementary school teachers have a relatively good understanding of STEM from a conceptual standpoint but still require reinforcement in the implementation of project-based learning and cross-disciplinary integration, particularly in areas with limited facilities such as 3T regions (frontier, outermost, and underdeveloped areas).

Furthermore, teachers' understanding of STEM teaching strategies reflects their readiness to implement STEM activities for elementary school students, with an average score of 3.68. However, the limited access to resources that effectively support STEM implementation remains a primary challenge. Every et al. (2025) emphasize the need to develop accessible and relevant STEM teaching materials tailored to the conditions in border regions. One of the highest-rated indicators in this study (3.86) pertains to using technology to support STEM activities in the classroom. Teachers actively utilize technological tools, such as educational software and interactive applications, to enhance students' learning experiences. It is supported by the findings of Sapounidis et al. (2024), which indicate that integrating technology into STEM education increases student motivation and engagement while facilitating more interactive and collaborative learning experiences. However, compared to the study conducted by Ogodo (2023) in urban areas, which showed a teacher readiness score of 4.20 for STEM implementation, the scores obtained by teachers in the border area in this study were still considered moderate. It indicated a resource access gap, including teaching materials, up-to-date references, and professional training.

Nevertheless, the lowest-scoring indicator (3.55) pertains to encouraging students to conduct independent experiments and research in STEM. While teachers recognize the importance of experimentation in STEM learning, they may lack confidence or adequate resources to support students in conducting independent research. It presents a challenge, as independent experimentation is a crucial component of STEM education that fosters critical and creative thinking skills. Research by Liu (2020) highlights that hands-on experimentation significantly enhances students' understanding of scientific and technological concepts. Further teacher training in instructional methods that promote exploration and inquiry-based learning is recommended to improve STEM implementation.

Additionally, adequate resource provision, such as experimental tools and relevant learning materials, is essential to support more effective STEM implementation in classrooms. The limited availability of basic laboratories, the scarcity of experimental materials, and restricted access to digital reference sources also pose significant barriers. In a study by McKenney and Reeves (2021), it was noted that teachers in border areas face challenges accessing journals, instructional modules, and online platforms supporting STEM due to internet connectivity issues and a lack of digital literacy training.

Another significant challenge is the lack of administrative support for STEM implementation, as indicated by the lowest-rated indicator (2.52) concerning teachers' perceptions of support from school administration. The insufficient institutional support regarding resources, training, and policies facilitating STEM integration may hinder teachers' initiatives in applying innovative and effective teaching methods. Research by Arafat et al. (2024) underscores the importance of school support in fostering a conducive environment for teacher professional development and implementing effective teaching practices. Additionally, the challenge of adapting STEM activities to students with varying abilities is also a concern, as indicated by a score of 3.29. Research by Yllana-Prieto et al. (2025) stresses that differentiation in STEM instruction is essential for addressing diverse learning needs, and teachers must be equipped with effective strategies to accommodate varying student abilities within the classroom.

The findings of this study indicate that elementary school teachers in the Indonesia-Malaysia border region have not yet developed a strong understanding of STEM implementation in primary education. In this context, teaching experience is not a major factor influencing teachers' comprehension of STEM. Several other factors contribute more significantly, including (1) standardized training and curriculum among teachers in border regions, (2) relatively equal access to learning resources, (3) similarities in teachers' educational backgrounds, and (4) contextual factors such as regional education policies and government support. Therefore, improving STEM comprehension among teachers in border areas requires targeted interventions, such as more intensive professional training, increased access to teaching resources, and strengthened institutional support to create a more enabling environment for effective STEM implementation in elementary schools.

Despite the significant findings, this study has several limitations. Firstly, the research focuses on teachers' self-reported data, which may introduce biases or subjective interpretations. Secondly, the study does not extensively analyze students' perspectives on STEM implementation, which could provide deeper insights into the effectiveness of teaching strategies. Thirdly, the study is limited to a specific geographical context, and findings may not be entirely generalizable to other border regions with different socio-economic conditions. Future research should consider conducting longitudinal studies to assess the long-term impact of STEM education on student outcomes. Additionally, further studies should explore the role of community and parental involvement in supporting STEM education and investigate innovative pedagogical approaches that address the challenges of resource limitations in border schools.

Conclusion

Teachers' understanding of STEM implementation in Bengkayang Regency's primary schools is moderate, with an average basic knowledge score of 3.84. While the frequency and methods of STEM implementation in teaching also fall within the moderate category (score of 3.71), teachers face significant challenges, as reflected in a low score of 2.98. The availability of resources and school support is rated as adequate (score of 3.66), though improvements are needed to enhance the effectiveness of STEM implementation. These findings suggest that longer teaching experience does not necessarily correlate with a better understanding of STEM-based teaching, highlighting the need for more intensive and relevant training programs and workshops to improve teachers' competencies. Therefore, professional development programs in the context of STEM education are highly recommended to address existing challenges and enhance the quality of primary education.

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Conflicts of Interest

The researchers affirm that there is no conflict of interest in the preparation and publication of this scientific article.

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Author Contributions

Totok Victor Didik Saputro: Conceptualization, writing – original draft, methodology, analysis editing, and submission; **Yessi Fatika Sari:** Writing – review & editing, validation, analysis, translation, and proofreading; **Silvester:** Validation, analysis, monitoring; **Christian Cahyaningtyas:** Data collection, data compilation; **Pery Jayanto:** Data compilation; and **Grecia Putri Harmoni:** Data collection, data compilation, and research documentation.

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