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Article

Principal Competency, Teacher Readiness, and Teacher Commitment in STEM Education Implementation: A Qualitative Study

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Abstract: The growing emphasis on Science, Technology, Engineering, and Mathematics (STEM) education in schools demands strong leadership and teacher commitment for effective implementation. However, challenges related to principal competency, teacher readiness, and their commitment have been identified as major obstacles to achieving desired outcomes through STEM initiatives. This qualitative study explores the competencies of school principals, teacher readiness, and the commitment required for successful STEM education. It aims to identify the principal competencies that influence teacher readiness and commitment, as well as the elements of teacher readiness that affect their commitment, and the specific aspects of teacher commitment crucial for STEM implementation. The study employs semi-structured interviews with teachers from selected schools, analyzed using thematic analysis to identify themes related to leadership competency, teacher preparedness, and commitment. Findings reveal that principals with competencies in STEM knowledge, management skills, and professional attributes are more likely to boost teacher readiness and commitment. Teacher readiness, particularly in terms of knowledge, skills, and attitude, plays a vital role in strengthening their commitment. Teacher commitment is driven by affective, continuance, and normative commitment, which are critical for STEM success. In conclusion, the study highlights the need to develop leadership competencies and teacher readiness as key strategies to enhance teacher commitment in STEM education. These findings have significant implications for education policy and professional development, calling for targeted interventions to support school leaders and teachers in effectively implementing STEM education.

Keywords: Principal competency; teacher readiness; teacher commitment; STEM education; instructional leadership; STEM Implementation

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Introduction

Science, Technology, Engineering, and Mathematics (STEM) education is increasingly gaining attention worldwide, including in Malaysia, as an effort to prepare students for the challenges of the 21st century (Ling et al., 2020; Sukumaran et al., 2021; Ndijuye & Tandika, 2020).STEM education in schools not only emphasizes knowledge and skills in science and technology but also the ability to solve problems and critical thinking needed in a dynamic workforce (Suryani & Prasetyo, 2023;Asena Türk & Nur Akcanca, 2021; Magasu, 2022). However, the effective implementation of STEM education does not solely depend on the curriculum and teaching content; it is also influenced by school leadership competencies (Rahim et al., 2020; Drozd, 2020; Yulia Rachmawati, 2021), teacher readiness (Dwi Kartini & Ari Widodo, 2020; Kartimi et al., 2021; Wu et al., 2022), and their commitment (Patton, 2020;Yang et al., 2023; Zugelder et al., 2021) to carrying out this initiative. In this context, the leadership of principals, teacher readiness, and teacher commitment are key factors that determine the success of STEM implementation at the school level.

However, there are existing research gaps in the implementation of STEM education in Malaysia that encompass several important aspects that have not been studied in depth. First, although there are studies showing inconsistent levels of teacher commitment, there is still a lack of research analyzing the factors influencing teacher commitment. Additionally, there is a need for research that investigates in greater depth the competencies of principals in supporting the implementation of STEM education. This is evidenced by previous findings, which showed inconsistent results, such as those by Salleh (2020) who reported high competencies, while (Nor Aidillina & Marinah, 2020) noted the weaknesses of principals in overcoming challenges. This clearly indicates the need to conduct studies that explore the requirements of principals to enhance teacher commitment in implementing STEM education.

Another aspect that needs to be explored is teacher readiness, as results from studies by Mustam and Adnan (2019); Nur Fatahiyah and Siti Nur Diyana (2020); Shamsuddin and Noorashikim (2021) recorded moderate levels of teacher readiness. This highlights the need for additional research to obtain information regarding the aspects necessary to improve teacher readiness.Therefore, the necessity to conduct this qualitative study is crucial for gaining a deeper understanding of the implementation of STEM education in Malaysia. By employing an interview approach with teachers, this research can directly delve into teachers' experiences and perspectives, which cannot be obtained through quantitative methods alone. This study aims to identify the factors that influence teacher commitment, teacher readiness, and principal competencies in successfully implementing STEM education.

The purpose of this study is to identify the factors that influence the success of STEM education implementation, specifically through the analysis of principal competencies, teacher readiness, and teacher commitment in teaching STEM subjects. The main objectives of this study are to answer three research questions related to STEM implementation in schools, namely: (i) What are the elements of principal competencies that influence teacher readiness and the commitment needed in the implementation of STEM education? (ii) What are the elements of teacher readiness that influence the commitment required for the implementation of STEM education? (iii) What are the elements of teacher commitment necessary for the successful implementation of STEM education?

The contribution of this study is to provide a clearer understanding of the relationship between principal competencies, teacher readiness, and teacher commitment in the context of STEM education. The findings of this study will contribute to a deeper understanding of how schools can strengthen leadership and teacher preparedness to enhance the effectiveness of STEM education implementation. Additionally, the results of this study may serve as an important reference for educational policymakers and professional development planners, especially in formulating more effective strategies to support the implementation of STEM education in schools.

Literature Review

1. Principal Competency in STEM Education

The principal plays a pivotal role as a leader in ensuring successful STEM education implementation, not only managing administrative tasks but also guiding the academic and instructional components (Basañes, 2020; Dewi, 2021; Mohd Yusoff & Ismail, 2021;Serpil Tuti Sari, 2019). In STEM contexts, principals guide and support teachers in implementing curricula aligned with technological advancements (El-Kassem, 2019; Wieselmann et al., 2021; Kulakoglu, 2023). A core competency in facilitating STEM success is decision-making. Principals must make data-driven decisions, particularly in securing resources essential for STEM implementation (Murphy, 2022; Rose et al., 2019; Wieselmann et al., 2021; McKay et al., 2018; Ortan et al., 2021) including budgets for training, materials, and technology (Haglund & Glaés-coutts, 2022; Rahim et al., 2020). Principals' timely, effective decisions help address challenges, like the shortage of qualified STEM teachers (Harron et al., 2022; Murphy, 2022; Rose et al., 2019). Clear communication is also key to principal leadership. Principals must articulate the school's vision for STEM, helping teachers understand their role in achieving these objectives and increasing commitment to STEM delivery. Effective communication creates a collaborative environment for teachers to exchange ideas and address teaching challenges (Haglund & Glaés-coutts, 2022; Liu et al., 2022; Kulakoglu, 2023). Effective resource management is another critical leadership skill. Principals allocate finances, teaching materials, and time for teacher development (Rahim et al., 2020;Casto, 2022; Vinnervik, 2022; Moreno et al., 2021; Gok, 2022) as studies indicate schools with adequate resources are more successful in STEM implementation. Competent principals ensure teachers have needed materials and access to professional development (Costa & Domingos, 2019 ; Kareemee et al., 2019; Vinnervik, 2022).

Finally, having a clear vision for STEM education is essential, fostering a shared goal among teachers, parents, and the broader community (Howard, 2020; Wieselmann et al., 2021; Morales et al., 2019) . Research indicates principals with these competencies significantly enhance teacher readiness and commitment to STEM (Baker et al., 2022; Booher et al., 2020). Principals who support teachers with training, resources, and open communication create an environment where educators feel prepared and committed to delivering STEM education effectively (Basañes, 2020; Dewi, 2021; Mohd Yusoff & Ismail, 2021; El-Kassem, 2019; Kulakoglu, 2023; Wieselmann et al., 2021). In summary, the principal's role as an instructional leader with strong decision-making, communication, and resource management skills, along with a clear STEM vision, is integral to successful STEM education implementation in schools.

2. Teacher Readiness in Implementing STEM Education

Teacher readiness is essential for successful STEM education implementation in schools, involving comprehensive knowledge of STEM subjects, pedagogical skills, access to resources, and opportunities for continuous training (Sungur-gul et al., 2023; Latifah Monnas, 2018; Mustam & Adnan, 2019; Domenici, 2022; Galadima et al., 2019; Nurul Sulaeman et al., 2020). These components contribute significantly to teachers' confidence and commitment in delivering effective STEM instruction (Hoon et al., 2022; Wu et al., 2022). STEM readiness requires teachers to possess deep subject knowledge, particularly in applying science, technology, and engineering in real-world contexts. Teachers who master STEM content are generally more confident and engaging (Fenton & Essler-Petty, 2019; Nur Fatahiyah & Siti Nur Diyana, 2020). However, limited in-depth knowledge, especially among non-specialists, often affects confidence and preparedness to teach STEM (Berisha & Vula, 2021; Nguyen et al., 2020).

Effective pedagogical skills are also crucial for STEM education, involving student-centered methods like problem-based and project-based learning. Such skills promote critical thinking and collaboration, but these approaches differ significantly from traditional methods and require ongoing training (Säde-Pirkko Nissilä et al., 2022; Terrie MGalanti & Nancy Holincheck, 2022) . Access to resources and professional development further supports teacher readiness. With suitable materials, equipment, and technological resources, teachers are more equipped to deliver impactful STEM lessons. Additionally, continuous training enhances instructional quality, with research linking relevant professional training to improved teaching outcomes in STEM (Gül et al., 2020; Säde-Pirkko Nissilä et al., 2022; Wu et al., 2022). Conversely, inadequate resources and training can hinder readiness and teaching effectiveness. Supporting and hindering factors in teacher readiness must also be addressed. Continuous training is critical, broadening teachers' content knowledge and introducing them to innovative methods (Morales et al., 2019; Sungur-gul et al., 2023).

School support, especially from principals, by allocating training time and resources, also fosters teacher preparedness (Sterrett et al., 2020; Kulakoglu, 2023;Vinnervik, 2022). Studies show that well-prepared teachers, equipped with knowledge, skills, and support, are generally more committed and motivated to teach STEM (Daher & Shahbari, 2020; Morales et al., 2019; Rukoyah et al., 2020). In contrast, low readiness can lead to stress and reduced enthusiasm, adversely affecting STEM education implementation. In conclusion, teacher readiness in STEM relies on knowledge, pedagogical skills, resources, and continuous support, collectively enhancing commitment and contributing to successful STEM education implementation in schools.

3. Teacher Commitment in Implementing STEM Education

Teacher commitment to STEM education is essential for effective STEM implementation in schools, encompassing affective attachment (Kareem & Thomas, 2022; Vaiopoulou et al., 2023; Zheng & Cheung Tse, 2021), professional responsibility (Milawati & Sholeh, 2020), and recognition of STEM's importance (Shume et al., 2022; Patton, 2020; Yang et al., 2023). These factors significantly shape teachers' readiness to adopt curriculum changes in STEM (Muhamad Ikhram et al., 2022; Net et al., 2022; Xiangyun Du & Chaaban, 2020). Affective attachment reflects teachers' enthusiasm for STEM subjects and commitment to student engagement (Yang et al., 2023). Teachers with strong affective ties gain satisfaction from student success and work to improve their methods for better outcomes. Research indicates that emotional connection to STEM positively impacts instructional quality and student motivation (Grillo & Kier, 2021; Kareem & Thomas, 2022; Patton, 2020). Such teachers, who personally value STEM, often bring creativity and dedication to their teaching. Teachers' professional responsibility is another core element of STEM commitment. Teachers with a robust sense of responsibility focus on preparing students for future challenges, which enhances STEM implementation (Thilagavathy et al., 2022; Thingwiangthong et al., 2021). This responsibility is reinforced through sustainable school leadership, such as principals who continuously provide professional development and resources (Huang & Hsin, 2023; Huong et al., 2022; Abdul Rahim et al., 2023). When schools offer such support, teachers feel empowered and committed to delivering effective STEM education (Faizah & Ruhizan, 2022; Wu et al., 2022).Understanding the importance of STEM also bolsters teacher commitment. Teachers aware of STEM's role in future careers are more driven to deliver quality instruction, recognizing STEM as essential for technological and industrial growth (Sungur-gul et al., 2023). Teachers motivated by STEM's significance prioritize equipping students with relevant skills and show greater dedication (Cabell et al., 2021; Yusoff et al., 2020).

Previous research also indicates that factors such as principal support, continuous professional development, and a conducive school environment play a role in influencing teachers' commitment to curriculum changes, including the implementation of STEM education. For instance, principals who provide support through training and resources boost teachers' confidence and encourage them to be more committed to teaching STEM (Kulakoglu, 2022). Teacher commitment to STEM has a direct impact on student learning outcomes (Kiral & Kaçar, 2017). Committed teachers are more likely to employ innovative teaching strategies, create stimulating learning environments, and address individual student needs. Research shows that students taught by committed teachers perform better in STEM subjects and are more enthusiastic about pursuing further education in these fields (Leary et al., 2020; Widiastuti et al., 2022). This demonstrates that teacher commitment is not only important for the effective implementation of STEM education but also for students' success in these areas.

Principal support, ongoing professional development, and a conducive school environment further enhance teachers' STEM commitment. Principals who actively support STEM foster teachers' confidence, encouraging dedication to STEM teaching (Kulakoglu, 2022). Research shows that committed teachers, who employ creative teaching methods and nurture student needs, improve student learning outcomes in STEM and spark student interest in these fields (Leary et al., 2020; Widiastuti et al., 2022). In conclusion, affective attachment, professional responsibility, and recognition of STEM's importance are vital in building teacher commitment to STEM. Strengthening these areas will support STEM education's future success in schools.

4. Challenges in Implementing STEM Education

STEM (Science, Technology, Engineering, and Mathematics) education has garnered global attention for its role in preparing students to face the challenges of the 21st century. However, implementing STEM education presents numerous challenges that impact its classroom effectiveness. Based on several studies, key obstacles include a lack of teacher knowledge and skills, varying attitudes toward STEM education, resource shortages, and difficulties in classroom management. One of the primary challenges is the lack of teacher knowledge and skills. Ling and Yasin (2022) found that rural schoolteachers' knowledge and skills in applying Design Thinking in STEM education were low. Many teachers are unprepared to adopt modern teaching methods that emphasize design thinking, an essential element in STEM education. This highlights the need for enhanced teacher training, particularly in rural areas where resources are often limited.

In addition, teachers' attitudes toward STEM education play a critical role in its successful implementation. Wei and Maat (2020), reported that the attitudes of primary school mathematics teachers toward STEM education were moderate, with no significant differences by gender. This moderate attitude reflects a lack of confidence regarding STEM's effectiveness. Wei and Maat (2020), emphasized that positive attitudes are essential in this educational transformation era, as they can lead to supportive behaviours that enhance STEM implementation. This finding suggests that educational ministries should make greater efforts to improve teachers' attitudes through continuous training and support. Moreover, the lack of resources and equipment is a significant challenge. Research by Ayten Pınar Bal (2021) revealed that while teachers acknowledge the importance of STEM education in boosting students' confidence and learning success, they struggle with classroom management and a lack of equipment. Although STEM activities can enhance learning quality, inadequate resources remain a considerable barrier, especially in schools with limited financial and technological support.

Furthermore, an overemphasis on exams and adherence to formal curriculum guidelines restricts STEM implementation. Pratama et al., (2022) found that in history lessons, teachers struggled to integrate STEM approaches due to curriculum requirements and exam pressures. This limits teachers' creativity in adopting more interactive, student-centered STEM methods, which can develop critical thinking skills. In summary, these challenges indicate that while STEM education has great potential to enhance student skills, obstacles related to knowledge, attitudes, resources, and curriculum constraints must be addressed. Greater efforts are needed to provide ongoing professional development for teachers, increase access to resources, and offer curriculum flexibility to encourage creative and innovative approaches. By tackling these challenges, STEM education in Malaysia and globally can become a more effective tool in preparing future generations for the challenges ahead.

Methodology

1. Research Design and Sampling

This study employed a qualitative approach using semi-structured interviews to gain in-depth insights into the competencies of school principals, teacher readiness, and teacher commitment in the implementation of STEM education. The qualitative approach was selected as it allows researchers to explore participants' experiences and perceptions in a more detailed and holistic manner. The study utilized purposive sampling, involving three STEM teachers, based on Creswell (2013) view that qualitative studies do not require large samples to obtain meaningful data, and a small number can provide deep insights into the phenomena under study. According to Mason (2010), in qualitative research, the number of participants depends on the purpose of the study, suggesting that three to five participants may be sufficient to achieve data saturation in specific contexts. The selected teachers were those with more than 10 years of teaching experience from both urban and rural schools.

2. Interview Protocol

The interview protocol for this study was developed in advance, with a set of questions designed for the interview sessions with the informants. The questions were divided into two sections: Section A focused on the informants' demographics, while Section B covered the competencies of principals in implementing STEM education, teacher readiness, and teacher commitment in STEM education delivery. The questions were open-ended, neutral, culturally sensitive, and easy to understand (Fauziah Ibrahim et al., 2021) approach was intended to ensure informants' comfort and generate rich data, leading to subsequent interview sessions.

The interview protocol included: (i) the title of the study, (ii) the main questions for each section, (iii) follow-up questions based on the main questions, and (iv) space for recording key messages and reflective notes. The interview questions, attached in Appendix A, were reviewed by three experts in STEM education and leadership for feedback. The questions were refined based on the expert input. A semi-structured interview method was employed, which involves active interaction between two or more individuals to guide the discussion in the context of the study (Shumar et al., 2023). In qualitative research, interviews aim to understand participants' perspectives and how they make sense of their lives, experiences, and cognitive processes (Brenner, 2006). In-depth semi-structured interviews were conducted, following Yin (2011) recommendations on speaking moderately, being non-directive, neutral, maintaining rapport, using the interview protocol, and analyzing data during the session.

Information from the informants was collected by arranging suitable dates and times for the interviews. The sessions were recorded using a voice recorder, with a focus on the key elements of principal competency, teacher readiness, and teacher commitment in the implementation of STEM education.

3. Data Collection

The textual data was provided through verbatim transcripts, which captured the dialogue word-for-word based on the interview recordings. According to Braun and Clarke (2014), thematic analysis is a flexible method for analyzing data. Through this approach, key themes are identified to facilitate deeper analysis. The interview transcripts were used to ensure the validity of the qualitative data, involving a member-checking process where participants reviewed the data.

4. Data Analysis

The aim of thematic analysis is to identify meaningful patterns or themes within the data. Braun and Clarke (2013) outline six steps in thematic analysis: (i) familiarizing oneself with the data, (ii) generating initial codes, (iii) searching for themes, (iv) reviewing themes, (v) defining and naming themes, and (vi) writing the report. In this study, verbatim transcripts of the three informants are attached in Appendix B. NVivo12 software was used for data analysis. Once the raw data was prepared via verbatim transcripts, the first step involved creating a new project in NVivo12 and importing the data. The next step was creating nodes, which serve as categories or indices to catalog the themes. Two types of nodes were utilized: free nodes and tree nodes. To code the data, the documents were read multiple times to gain a deep understanding of both the explicit and implicit meanings.

The coding process began by opening the document to be coded, with the content displayed in the "detail view." Appropriate nodes were selected by opening the node folder in the "list view" to display the list of node names. Relevant words or paragraphs were then dragged to the corresponding node. Using NVivo12's model feature helped display the findings visually, clarifying the thematic patterns identified during the analysis.

Findings

1. Elements of Principals' Competencies Needed in the Implementation of STEM Education

Principal's Competency

The findings of this study highlight that the competency of school principals in implementing STEM education plays a significant role in the success of STEM programs in schools. Based on interviews with the informants, three key elements of principal competency were identified: knowledge, skills, and attributes.

i. Knowledge

The principal's knowledge competency is seen as a crucial aspect in supporting the implementation of STEM. Informant 1 stated that a knowledgeable principal can effectively communicate information through various channels, as noted:

> *"Usually, the administrator conveys STEM information via Telegram groups, and to the students, the principal shares information through weekly programs or activities related to STEM. It's also announced through notices on the school bulletin board"* (Informant 1).

In-depth knowledge enables the principal to guide teachers, especially new teachers who lack experience in conducting STEM projects:

> *"Yes, when the administrator is knowledgeable, they understand the project flow. They can provide ideas and guidance, especially for inexperienced teachers, as the administrator has more experience"* (Informant 1).

ii. Skills
In addition to knowledge, the principal's skills in STEM education were also emphasized. Informant 1 explained that an experienced and skilled principal can assist teachers:

> *"They understand the project flow, provide ideas and guidance, especially for new teachers who lack experience, so the administrator plays a role in helping them"* (Informant 1).

This support ensures that new teachers receive proper guidance in implementing STEM projects. Informant 3 also stressed this point:

> *"The administrator needs to have knowledge and skills so that they understand the challenges teachers face in making a program successful*" (Informant 3)

iii. Attributes
Lastly, the principal must possess suitable attributes, such as providing moral support and opportunities for teachers to be creative. Informant 1 mentioned:

> *"The administrator truly supports STEM. They set compulsory integrated STEM activities for each class and also organize integrated STEM-based project-based learning (PBL) competitions between classes, inviting other schools to observe."* (Informant 1)

This moral support helps teachers feel appreciated and more motivated in implementing programs. However, challenges remain, as expressed by Informant 2:

> *"Only when they receive a letter about attending a STEM course will they send teachers. They don't go for teaching and learning exposure, but just for STEM competitions."* (Informant 2)

Overall, these findings emphasize that principals with the appropriate knowledge, skills, and attributes are critical factors in enhancing teachers' readiness and commitment to STEM education in schools.

2. Elements of Teacher Readiness in the Implementation of STEM Education

Teachers' Readiness
The findings of this study indicate that teachers' readiness to implement STEM education is influenced by three main elements: knowledge, skills, and attitude.

i. Knowledge
The interviewed teachers exhibited varying levels of knowledge about STEM. For instance, Informant 1 mentioned:

> *"I understand the concept of STEM, which includes Science, Technology, Engineering, and Mathematics, and how these subjects are interconnected."* (Informant 1)

This teacher also grasped the concept of Integrated STEM, which involves the integration of multiple subjects to relate knowledge to real-life applications:

"Integrated STEM involves the integration of different subjects." (Informant 1)

In contrast, other teachers had only a basic understanding of STEM, as reported by Informant 2:

"STEM isn't emphasized at school. I only know about it from fellow teachers who attended courses."(Informant 2)

ii. Skills

Teachers' skills in planning and implementing STEM activities were also recognized, particularly in using approaches like problem-based learning (PBL) and hands-on activities. Informant 1 explained:

"I use a hands-on and project-based learning (PBL) approach, for example, during the maze project, where students worked in groups to build a model."(Informant 2)

However, there were limitations in terms of infrastructure and teacher readiness, as noted by Informant 2:

"*In subjects like Design and Technology (RBT), for example, coding is too advanced; it can't be implemented in schools yet."* (Informant 2)

iii. Attitude

Teachers' attitudes towards STEM were generally positive, with some expressing a desire to explore the STEM field further and overcome the challenges they faced. For instance, Informant 1 said:

"I have a positive attitude towards STEM implementation and believe it offers students the opportunity to link knowledge with practical experiences." (Informant 1)

Nevertheless, challenges such as time and administrative support were highlighted:

"The challenge is that teachers can incorporate STEM into their teaching, but the issue now is the extensive syllabus" (Informant 2).

Overall, teachers' knowledge, skills, and attitudes play a crucial role in determining their readiness for implementing STEM education. Teachers with a good understanding, appropriate skills, and a positive attitude towards STEM are more likely to successfully carry out STEM activities.

3. Elements of Teacher Commitment Required for the Successful Implementation of STEM Education

Teachers' Commitment

The findings of this study indicate that teachers' commitment to the implementation of STEM education is divided into three main elements: affective commitment, continuous commitment, and normative commitment.

i. Affective Commitment

Affective commitment refers to teachers' emotional attachment to their tasks, which drives them to remain engaged in STEM implementation. For instance, Informant 2 demonstrates high commitment by stating:

"When we don't know how to teach, we need to outsource that knowledge ourselves." (Informant 2)

This shows that despite a lack of support, teachers proactively seek solutions externally. Teachers also emphasize their role in solving problems creatively, as noted by Informant 3:

"Automotive skills, like welding, are used to fix broken goals with welding." (Informant 3)

Additionally, teachers' efforts to participate in STEM activities are evident through their involvement in events and competitions, even with limited formal exposure. For example, Informant 2 mentioned:

"If there are competitions organized by certain parties, especially the administration head, the school will ask teachers to bring students to participate in STEM." (Informant 2)

ii. Continuous Commitment

Continuous commitment involves teachers' desire to keep developing in STEM education despite facing constraints or challenges. Informant 2 explained:

"I only learned about STEM when my friends returned from a course and shared what they learned, and that's when I found out what STEM really is." (Informant 2)

This indicates that even if teachers are not given direct exposure, they make an effort to gain knowledge through colleagues and take initiative to learn on their own.

iii. Normative Commitment

Normative commitment refers to teachers' sense of moral responsibility towards teaching and implementing STEM. Informant 2 emphasized:

"If you want to teach, you need to find out on your own." (Informant 2)

This shows how teachers take the initiative to bring in external trainers to support them, reflecting their willingness to take responsibility for implementing STEM at school, even without full administrative support. Additionally, Informant 1 noted:

"Teachers move from one station to another to observe hands-on activities related to science, the science projects students are working on, and we teach what we teach students, we teach fellow teachers." (Informant 1)

In addition, the interview findings indicate the challenges and successes of implementing STEM education. Here are the inputs provided by the informants:

"Administrators need to have knowledge and skills so that they understand the difficulties teachers face in making a program successful" (Informant 3)

"In my opinion, at the school, there wasn't widespread exposure; only a few teachers were involved and aware of it. We thought it was something minor, just a short-term program like STEM-related competitions. So, the school sent teachers and students to participate, but that's where it ended. They need to have the knowledge, then they can explain it, and they need to know how to carry out and monitor the program." (Informant 2)

"Administrators need to give teachers the opportunity to be creative, provide moral support, or help find external parties that can assist. That way, it's not just the teachers and students; there is outside help as well." (Informant 1)

"Even the senior assistants and administrators don't think, 'Oh, our teachers don't understand, we should try to find external resources.' They really rely on us to make the effort. We've explained the problem to them, but that's as far as it goes, meaning they expect us to figure it out ourselves." (Informant 2)

"There are no special infrastructure facilities for STEM." (Informant 3)

"So far, they support what's in the syllabus, but when it comes to supporting STEM, there's none." (Informant 2)

"Besides finances and time, administrators need to delegate tasks to teachers. If we want to implement STEM, we must go all out with the students, and teachers who have the potential to advance STEM in the school should be identified. The workload of those teachers needs to be reconsidered." (Informant 3)

Discussion

The findings from the interviews provide valuable insights into the dynamics of STEM education implementation, particularly emphasizing the crucial roles of school principals and teachers' readiness to commit.

1. Principal Competency

This study identifies three key elements of principal competency—knowledge, skills, and attributes—as important factors influencing teachers' readiness and commitment. This aligns with the literature highlighting the significance of leadership in the educational context. For instance, studies by Basañes (2020); Dewi (2021); Mohd Yusoff and Ismail, (2021) emphasize that principals with a solid understanding of STEM can effectively communicate and implement initiatives, which corresponds with Informant 1's perspective on conveying STEM information through various channels. The literature suggests that principals must not only possess subject-specific knowledge but also have a clear understanding of how to support teachers through guidance and professional development initiatives.

The lack of knowledge and skills among administrators, as noted in the findings, is consistent with other studies that show that without adequate training, principals may struggle to support their teachers effectively (Ortan et al., 2021). This gap underscores the need for targeted professional development programs to enhance principals' competencies in STEM education. Such programs could focus on building practical knowledge and skills to enable administrators to better facilitate STEM initiatives. In conclusion, the role of the principal as an instructional leader with skills in decision-making, communication, resource management, and a clear vision is key to ensuring the successful implementation of STEM education in schools (Baker et al., 2022; Booher et al., 2020)

2. Teacher Readiness

This study also indicates that teachers' readiness is influenced by their knowledge, skills, and attitudes toward STEM. The varying levels of knowledge among teachers, as mentioned by Informant 1, highlight a significant inconsistency in readiness. These findings are consistent with previous studies suggesting that teachers' understanding of STEM concepts is essential for successful implementation (Sungur-gul et al., 2023). The positive attitudes shown by some teachers indicate a readiness to embrace STEM education; however, challenges such as limited exposure and resources remain barriers.

Furthermore, Informant 2's concerns about the lack of infrastructure underscore the importance of adequate resources and training for teachers. The literature shows that professional development in pedagogical approaches, such as problem-based learning (PBL), can enhance teachers' skills and confidence in delivering STEM education (Domenici, 2023). Therefore, there is an urgent need for comprehensive training programs to equip teachers with the necessary skills to overcome these barriers. Research indicates that teachers who are more prepared in terms of knowledge, skills, and support are more likely to demonstrate strong commitment to teaching STEM (Daher & Shahbari, 2020; Rukoyah et al., 2020; Sharida et al., 2024).

Overall, teachers' readiness to implement STEM education relies on several key elements, including subject knowledge, pedagogical skills, access to resources, and ongoing support and training. These elements collectively contribute to teacher commitment, which ultimately affects the success of STEM education implementation in schools.

3. Teacher Commitment

Teacher commitment, divided into affective, continuous, and normative commitment, reflects the complex motivations behind their involvement in STEM education. The proactive attitudes displayed by teachers in seeking external knowledge, as noted by Informant 2, are commendable and reflect a high affective commitment to their roles. This aligns with findings from Kareem and Thomas (2022); Vaiopoulou et al., (2023) which state that a strong emotional connection to teaching significantly drives educators' professional growth. However, the findings also indicate that without adequate support from school administrators, such as moral support and opportunities for creative expression, teachers may struggle to fully realize their commitments. The literature suggests that creating a supportive environment is critical for enhancing teachers' normative commitment, as it strengthens their sense of responsibility towards student learning and program success (Huong et al., 2022; Thilagavathy Sethuramah et al., 2022; Wu et al., 2022).

Overall, teacher commitment to STEM teaching, encompassing affective commitment, professional responsibility, and recognition of the importance of STEM, is a critical factor in ensuring the success of STEM education in schools. Therefore, the factors supporting this commitment should continue to be strengthened to ensure the future success of STEM education.

Conclusion

The findings from this study underscore the significant roles of principal competency, teacher readiness, and teacher commitment in successful STEM education implementation. Principals with strong knowledge, skills, and attributes positively influence teacher readiness and commitment, aligning with previous research highlighting the importance of effective educational leadership (Basañes, 2020; Dewi, 2021; Ortan et al., 2021). Teacher readiness, however, remains variable, influenced by subject knowledge, pedagogical skills, and resource availability. Limited exposure and infrastructure highlight the need for comprehensive training programs, echoing findings from Domenici (2023) and (Sungur-gul et al., 2023). Teacher commitment, especially affective and normative, emerges as a crucial motivational factor for sustained engagement in STEM education, furthered by support from school leadership (Kareem & Thomas, 2022; Vaiopoulou et al., 2023).

This study implies that strengthening both principal and teacher competencies through professional development and resource allocation can enhance STEM education outcomes. Future research could explore targeted interventions to address specific gaps in knowledge and skills, as well as strategies to improve resource access and training opportunities. Additionally, investigating long-term impacts of leadership support on teacher commitment and STEM teaching efficacy would provide valuable insights for policy and educational program design.

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