A Study on Principal Competency, Teacher Readiness, and Teacher Commitment in Implementing STEM Education

Sariati Talib, Bity Salwana Alias and Mohd Effendi @ Ewan Mohd Matore

Abstract **– This quantitative study investigates the interrelationships between principal competency, teacher readiness, and teacher commitment in the context of STEM education implementation. Recognizing the critical role of school leadership in educational outcomes, this research evaluates how the knowledge, skills, and attributes of principals influence the readiness and commitment levels of teachers towards STEM disciplines. Data were collected through surveys from 316 secondary school STEM teachers in Melaka, providing a robust dataset for analysis. Each variable, namely principal competency, teacher readiness, and teacher commitment was assessed through detailed sub-constructs to gauge specific aspects of each domain. The findings reveal that principal competency is high, indicating strong leadership qualities that potentially enhance STEM education outcomes. In contrast, teacher readiness is moderate, suggesting a need for further development in teacher training and resources to fully engage in STEM teaching. Teacher commitment is notably high, which reflects a strong dedication among teachers to implement STEM despite varying levels of readiness. The study underscores the necessity for targeted interventions aimed at boosting teacher readiness, such as professional development programs and resource allocation, to leverage the high commitment levels. Furthermore, it highlights the significant impact of principal leadership on fostering an environment conducive to effective STEM education. These insights are crucial for policymakers and educational leaders aiming to improve STEM education through strategic enhancements in principal training and support systems. The implications of these findings advocate for prioritizing principal competency development as a key strategy to strengthen both teacher readiness and commitment in the successful implementation of STEM education**

Keywords **– Principal competency, Teacher readiness, Teacher commitment, STEM education implementation, Professional development, School leadership, Educational interventions.**

I. INTRODUCTION

In the ever-evolving world of education, Science, Technology, Engineering, and Mathematics (STEM) education has become a major focus in the global education agenda. The emphasis on STEM education is recognized as a key factor in empowering students with the necessary skills for the knowledge-based economy of the 21st century (Magasu, 2022; Murphy, 2022; Ndijuye & Tandika, 2020).

In Malaysia, initiatives to enhance STEM education have gained serious attention in national education policies, considering the need to produce a more skilled workforce in STEM fields (Foi & Kean, 2022; Lasaraiya et al., 2021; Nor Aidillina Mohd. Ramli & Marinah Awang, 2020).

In the context of implementing STEM education programs, the role of principals as school leaders is critical in setting the direction and ensuring the success of these initiatives. Effective leadership in STEM education requires leaders who can guide and inspire teachers to adapt innovative STEM teaching methodologies (Bhutto et al., 2023; Geiger et al., 2023; Liu et al., 2022). This aligns with the need to enhance collaboration among stakeholders within the education system (Magasu, 2022; Ndijuye & Tandika, 2020; Velasco, 2022).

Furthermore, teachers' readiness to implement STEM education also plays a crucial role. This readiness is not limited to subject knowledge alone but also includes pedagogical skills and the appropriate attitudes required to teach STEM subjects (Burton, 2022; Holincheck & Galanti, 2023; P. Wu et al., 2022). Studies have shown that teachers with a deep understanding of STEM pedagogy are more likely to actively engage students in the learning process (Arlinwibowo et al., 2023; Papagiannopoulou et al., 2023; Shidiq & Nasrudin, 2021).

Teachers' commitment to STEM education is another factor that cannot be overlooked. This commitment can be divided into several aspects, namely affective commitment, continuous commitment, and normative commitment, all of which influence teachers' effectiveness in implementing STEM education (Papagiannopoulou et al., 2023; Shume et al., 2022; Yang et al., 2023). Teachers with high levels of commitment tend to be more innovative in integrating STEM elements into their teaching, which indirectly enhances students' interest and achievements in this field (Patton, 2020; Smith et al., 2022).

This study aims to identify the level of principal competency, teacher readiness, and teacher commitment in implementing STEM education. By understanding the relationship between these three dimensions, this research is expected to provide insights into the dynamics that influence the successful implementation of STEM education in schools. The findings of this study are anticipated to provide valuable information for policymakers, school management, and other stakeholders in formulating more effective strategies to advance STEM education.

A comprehensive assessment of principal competency, teacher readiness, and teacher commitment will be conducted using a quantitative methodology, which allows for systematic data collection and objective analysis of the relationships between the study variables. Therefore, this article aims to bridge the knowledge gap by exploring how elements such as principal competency, teacher readiness, and teacher commitment interact to influence the success of STEM education implementation, ultimately contributing to the development of more meaningful and effective education policies in Malaysia.

Sariati Talib, Institut Pendidikan Guru Kampus Pendidikan Teknik (sariatitalib@gmail.com),
Bity Salwana Alias, Universiti Kebangsaan Malaysia (bity@ukm.edu.my),
Mohd Effendi @ Ewan Mohd Matore, Universiti Kebangsaan Malaysia (effendi@ukm.edu.my)

II. PROBLEM STATEMENT

This study focuses on the issue of limited teacher commitment towards STEM education in Malaysia, which has been identified as a major barrier to the effective institutionalisation of STEM culture in schools. Although the importance of STEM education has been emphasised in various national education policies, a significant gap remains between policy intentions and grassroots-level implementation. Teachers are often reported to demonstrate a lack of strong commitment in delivering STEM-based teaching and learning (T&L).

Findings from the Student STEM Index (Indeks STEM Murid – ISM) conducted by the Ministry of Education Malaysia in 2022 further reinforce these concerns. The study assessed the level of STEM culture in Malaysian schools by examining several key aspects, including teacher commitment to STEM T&L, the availability of infrastructure, and school leadership and management. The results revealed that the overall level of STEM culture across the country remains low, indicating that both teacher commitment and school management involvement in STEM implementation are still unsatisfactory. Based on these findings, the state of Melaka was selected as the research location, as it recorded the lowest performance in STEM culture compared to other states in Malaysia.

Internationally, this issue has been discussed following findings from several researchers. These findings identify various factors that influence teachers' commitment to implementing STEM education. These factors include a lack of training related to STEM (Boz, 2023), insufficient support from principals (Patton, 2020), low confidence (Yang et al., 2023), lack of interest (Diego-Mantecon et al., 2021), and a shortage of resources or infrastructure (Samara & Kotsis, 2023) as well as a lack of readiness (Shume et al., 2022).

Furthermore, research in Malaysia has shown that teachers' commitment levels range from low to moderate across various dimensions including professional dedication (Z. H. Wan et al., 2023), goal orientation and school organizational culture (Atiqah et al., 2024; Vetriveilmany, 2024) as well as the implementation of school-based assessments (Azizah Mohd Mohyin, 2021). Studies have also noted student achievement (James Billy & Taat, 2020) and organizational structure (Mohamad Firdaus Ahmad et al., 2023) as well as the environment and professional aspects (Kavitha Ranganatha et al., 2023). However, these studies in Malaysia tend to examine commitment in various aspects and less focus is given to teachers' commitment in STEM education. This situation underscores the urgent need for more detailed research on teachers' commitment in implementing STEM education.

In terms of leadership, previous research indicates a deficiency in principals' competencies to lead and manage STEM education, both domestically and internationally. Research by Hatisaru et al. (2023) has identified a lack of disciplinary knowledge in STEM education, emphasizing the need for principals to possess deep understanding and skills in managing STEM education. Kulakoglu and Kondakci (2023) highlighted principals' limitations in their knowledge of STEM education, abilities to manage STEM programs, and leadership attributes necessary to overcome challenges, resource shortages, and infrastructure.

In Malaysia, studies by Nor Aidillina Mohd. Ramli and Marinah Awang (2020) show that principals with inadequate capabilities to encourage and implement STEM education, particularly those with a background in STEM, are more likely to understand and support the implementation of STEM initiatives. Additionally, research by Salleh Ismail Kong (2020) confirms that a lack of competencies among principals also affects the effectiveness and motivation of teachers in implementing STEM education.

Research in Malaysia has revealed deficiencies and weaknesses in principals' competencies across various fields, including financial management, technology utilization, conflict management, and sensitivity to change as noted by Harun et al. (2024) transformational leadership and change management explored by Faizuddin et al. (2022), and communication skills, openness, and strategic knowledge highlighted by Dexter Silam et al. (2020). Studies by Norliza Samad et al. (2022) examined aspects of leadership, pedagogy, planning, decision-making, supervision, and mentoring, while Zatun Najahah and Muhammad Faizal (2024) knowledge, skills, and leadership attributes in a cross-cultural context. Aizuddin Md Rami et al. (2021) focused on leadership in rural communities, and Liang Fei Shin (2020) concentrated on change leadership. Although these studies cover a wide range of aspects, there is limited focus on STEM education. This underscores the urgent need for more in-depth research on principals' competencies in managing STEM education in Malaysia, given the limited scope of current studies.

Regarding teacher readiness, research findings indicate that the level of preparedness among teachers to implement STEM education is low to moderate, both domestically and internationally. Internationally, various factors such as a lack of knowledge and skills (Huong et al., 2022; Leung, 2023; D. Wu et al., 2022) insufficient training and professional development (Hang et al., 2024; Karunarathne, 2024; P. Wu et al., 2022) and a shortage of resources and infrastructure (Hang et al., 2024; Huong et al., 2022; Mabsutsah et al., 2023) have been identified as contributors to this low readiness. Additionally, factors such as inadequate support (Shidiq & Nasrudin, 2021; P. Wu et al., 2022), demographic issues and time constraints (Mabsutsah et al., 2023), and a lack of confidence and access (Syed Abdul Manan & Anas Hajar, 2024) also affect this readiness.

Similarly, domestic research findings indicate that the level of readiness among teachers to implement STEM education is low to moderate, influenced by various factors. These include a lack of training and professional development (Manibarathi Nagaretnam & Muhammad Sofwan Mahmud, 2022; Mohd Alfouzii Nasir et al., 2023; Nur Nadhirah Ahamad Said et al., 2024; Rahimah Jamaluddin et al., 2023; Shamsuddin Muhammad & Noorashikim Noor Ibrahim, 2021; Teoh Sian Hoon et al., 2022) insufficient knowledge and skills (Abdul Latif Ahmad et al., 2023; Khusnidar Muhammad Daud, 2019; Siti Yusnidar et al., 2021; Suganti Ealangov & Khairul Azhar Jamaludin, 2024) and a shortage of resources and infrastructure (Manibarathi Nagaretnam & Muhammad Sofwan Mahmud, 2022; Mohd Alfouzii Nasir et al., 2023; Nur Nadhirah Ahamad Said et al., 2024).

Additionally, issues related to attitudes and motivation (Mohd Ikhlas Abd. Halim et al., 2023), as well as time

constraints and lack of support (Nur Nadhirah Ahamad Said et al., 2024) also play a role. This situation underscores the need for more in-depth research to understand teachers' readiness in terms of knowledge, skills, and attitudes comprehensively.

Therefore, the objectives of this study are threefold. it aims to identify (i) the level of teacher commitment in implementing STEM education, (ii) the level of principal competency in managing and facilitating STEM education and (iii) the level of teacher readiness to engage in and effectively deliver STEM education. These objectives are critical for understanding and enhancing the implementation of STEM education across schools.

III. LITERATURE REVIEW

Principal Competence for STEM Education

Previous studies have depicted a general understanding of the importance of STEM education, yet there remains a deficiency in the knowledge, skills, and leadership qualities required by principals to efficiently manage and lead the implementation of STEM education.

Hatisaru et al. (2023) discussed the differences in focus between principals and educators towards discipline knowledge and basic skills in Australia. On the other hand, Kulakoglu and Kondakci (2023) demonstrated a lack of understanding and infrastructure to handle STEM education in Turkey. Research by Salleh Ismail Kong (2020) the influence of principals' leadership styles in urban and rural areas of Sabah on teachers' readiness for STEM education.

Nor Aidillina Mohd. Ramli and Marinah Awang (2020) along with Harun et al. (2024), found that deficiencies in management and infrastructure could directly affect students' interest and school management. Faizuddin et al. (2022) and Dexter Silam et al. (2020) emphasized the importance of knowledge and skills in professional development and communication to overcome leadership weaknesses. Norliza Samad et al. (2022) highlighted a lack in knowledge, skills, and attitudes essential for effective management.

Zatun Najahah and Muhammad Faizal (2024) outlined the need for improved leadership skills, enhanced communication, and community engagement in school development for successful programs, particularly intercultural programs. Aizuddin Md Rami et al. (2021) suggested that leadership skills in the community be enhanced by developing talents and skills such as communication, relationship building, and value creation to help develop rural communities.

Liang Fei Shin (2020) asserted the need for principals to strengthen their leadership capabilities and enhance teachers' self-efficacy through intensive training in change competencies for principals. All these findings stress the immediate need for more comprehensive and focused development of principals' leadership competencies.

Previous study findings indicate that improvements in principals' competencies play a crucial role in enhancing teachers' readiness and commitment to implementing STEM education. This awareness opens avenues for deeper research into how competencies like knowledge, skills, and leadership attributes of principals can serve as primary drivers and crucial components to bolster teachers' readiness and commitment. This suggests the need for professional development programs that strengthen principals' ability to lead effectively in a dynamic educational environment.

Moreover, the awareness of the need for a more integrated and inclusive approach to STEM education, as advocated by Zatun Najahah and Muhammad Faizal (2024), highlights the potential for a leadership model that encompasses intercultural interactions and supports diversity in education. By further exploring the level of principals' competencies in the context of implementing STEM education, we can develop more practical strategies to address the educational challenges of the 21st century.

Teacher Readiness for STEM Education

Previous studies have revealed various challenges faced by teachers in implementing STEM education. Hang et al. (2024) found that a lack of training and resources is a major barrier to effective STEM teaching in Northern Vietnam. Yang et al. (2023) reported that K12 teachers in China show high emotional readiness but lack behavioural skills necessary for effectively implementing STEM education. In Hong Kong, Leung (2023) detected a shortage of STEM knowledge among early childhood education teachers.

In Sri Lanka, Karunarathne (2024) found that teachers have low awareness of STEM/STEAM, while Mabsutsah et al. (2023) reported difficulties in integrating STEM in junior high schools in Indonesia. Shidiq and Nasrudin (2021) highlighted a shortage of STEM courses in higher education institutions, affecting the preparation of future teachers. In Kazakhstan, Syed Abdul Manan and Anas Hajar (2024) reported language barriers that hinder STEM teachers from teaching in English.

In Malaysia, similar challenges were observed. Shamsuddin Muhammad and Noorashikim Noor Ibrahim (2021) found that STEM teachers along the coastal areas of Kelantan have only moderate readiness but require more effective professional training. Abdul Latif Ahmad et al. (2023) reported a lack of STEM knowledge among physical education teachers in Batu Pahat, although they have high motivation and behavioural intentions. Mohd Ikhlas Abd. Halim et al. (2023) discovered a moderate interest and attitude towards STEM among preschool teachers in Sabah. Hoon et al. (2024) emphasized the importance of mathematical resilience to help rural students succeed in STEM. Suganti Ealangov and Khairul Azhar Jamaludin (2024) reported that community college lecturers have high readiness for project-based learning but lack in-depth knowledge.

Other studies include one by Manibarathi Nagaretnam and Muhammad Sofwan Mahmud (2022) that recorded challenges faced by primary school mathematics teachers in integrating 21st-century elements. Rahimah Jamaluddin et al. (2023) found a lack of training in STEM integration among Home Science teachers, while a study by Siti Yusnidar et al. (2021) reported that teachers feel a lack of institutional support in implementing STEM. Nur Nadhirah Ahamad Said et al. (2024) study described a shortage of teacher preparedness in implementing computational thinking. Mohd Alfouzii Nasir et al. (2023) study showed

that STEM practices among secondary school teachers in the Southern Zone of Malaysia are still at a moderate level.

Lastly, Abdul Latif Ahmad et al. (2023) examined the readiness of teachers to integrate STEM in physical education and found a lack in STEM knowledge aspects. Khusnidar Muhammad Daud and Mazlina Che Mustafa (2022) study showed that the readiness of teachers to implement STEM in physical education is moderate but requires more training. The latest study by Suganti Ealangov and Khairul Azhar Jamaludin (2024) and Mohd Ikhlas Abd. Halim et al. (2023) highlighted the importance of professional development interventions to enhance teachers' proficiency in STEM education.

Previous research has demonstrated that despite awareness of the importance of STEM education, many teachers continue to face difficulties in its implementation. One major barrier frequently reported in international studies is the lack of training and resources. For instance, research conducted by Hang et al. (2024) in Northern Vietnam found that insufficient training and resources were major obstacles. In China, P. Wu et al. (2022) reported that although teachers have strong emotional readiness, they often lack the behavioural skills necessary for effectively implementing STEM education.

In Malaysia, research by Shamsuddin Muhammad and Noorashikim Noor Ibrahim (2021) found that STEM teachers in Kelantan are only moderately ready and require more intensive professional training. This reflects similar findings from Abdul Latif Ahmad et al. (2023), who reported a lack of STEM knowledge among physical education teachers in Batu Pahat, despite their high motivation and behavioural intentions. Studies conducted in various countries reveal clear commonalities regarding the challenges and readiness of teachers in implementing STEM education. The findings indicate that a deficiency in adequate professional training is a major barrier. For example, both P. Wu et al. (2022) and Leung (2023) highlighted a lack of specific STEM training and behavioural readiness as significant obstacles.

Additionally, insufficient resources and infrastructure also pose common problems. Research by Hang et al. (2024) and Karunarathne (2024) emphasized that these shortages not only hinder effective STEM teaching but also affect teachers' motivation and confidence. Furthermore, studies by Mabsutsah et al. (2023) in Indonesia and those conducted in Malaysia show that despite a desire to integrate STEM, a lack of understanding and curriculum support often becomes an obstacle.

Although there are many similarities, there are also significant differences in the findings concerning teachers' readiness for STEM education. These differences arise from methodological approaches, geographical contexts, and target populations. For example, the quantitative methodology used by P. Wu et al. (2022) contrasts with the qualitative approach by Leung (2023) which provides deeper insights into the subjective challenges faced by teachers.

Geographical contexts, as shown in the study by Hang et al. (2024) in Vietnam, illustrate unique challenges faced by teachers in rural areas, different from those in urban areas in developed countries. This highlights how socio-economic factors and infrastructure can influence teachers' readiness and capabilities. Understanding these research outcomes is crucial for designing STEM education interventions tailored to local needs and challenges. This research also stresses the need for a more integrative approach involving enhancements in infrastructure, teaching resources, and professional development of teachers, which are vital for creating an environment that supports teachers in effectively implementing STEM education.

Therefore, teachers' readiness for STEM education is critical in determining the success of integrating STEM into the educational curriculum. Considering the similarities and differences in these findings, organized and strategic actions are required at the global level to address these issues, including improvements in teacher training, resources and infrastructure, and better integration of education with industry needs.

Teacher Commitment in STEM Education

Previous research has delved deeply into the factors influencing teachers' dedication to implementing STEM education. Boz (2023) found that elementary school teachers lack sufficient training, highlighting the need for more intensive professional development. Mwesiga and Masulu (2020) reported that despite high commitment among teachers in Tanzania, they are hindered by a lack of motivation, training, and institutional support. Owais et al. (2023) showed a positive relationship between psychological capital and organizational commitment among university lecturers. Patton (2020) discovered that teachers' willingness to accept changes affects their effectiveness in implementing STEM education in urban areas.

Diego-Mantecon et al. (2021) reported that teachers in Spain have a low readiness to integrate mathematics into STEAM projects. Meanwhile, Shume et al. (2022), found that a lack of practical training impedes the effectiveness of engineering design teaching among rural teachers. Research by Yang et al. (2023) indicates that teachers' confidence in their roles as educators plays a critical role in enhancing their dedication to STEM teaching. Aminah Jekri and Crispina Gregory K Han (2020) emphasized the impact of teaching experience in shaping motivation and the implementation of STEM education, noting that intrinsic motivation is higher than extrinsic motivation.

Further research by Atiqah et al. (2024) shows a significant and strong relationship between principals' distributed leadership and teacher commitment. Vetriveilmany (2024) reported that emotional intelligence of leaders is a major factor in enhancing teachers' organizational commitment. Azizah Mohd Mohyin (2021) found that transformational leadership by principals positively correlates with teacher commitment in the implementation of School-Based Assessment (PBS).

A study by James Billy and Taat (2020) indicates that a conducive school culture enhances teacher commitment. Mohamad Firdaus Ahmad et al. (2023) reported gender differences in organizational commitment among public and private sector workers in Malaysia. Kavitha Ranganatha et al. (2023) discuss the influence of authentic leadership on motivation and commitment of primary school teachers. Lastly, research by L. H. Wan et al. (2023) emphasizes the importance of collaboration among teachers from various

disciplines in enhancing the effectiveness of transdisciplinary projects in STEAM education.

Results from previous studies provide valuable information on how various factors can affect teachers' commitment to STEM education and how this understanding can be used to improve STEM education overall. Research by scholars such as Boz (2023), Mwesiga and Masulu (2020) and Owais et al. (2023) has highlighted several key elements that can enhance teachers' dedication to STEM education, involving both individual and organizational aspects.

Continuous and comprehensive professional development has proven to be a crucial factor in assisting teachers to integrate STEM education. Effective training not only boosts teachers' confidence but also deepens their understanding of the best ways to implement innovative and effective STEM methodologies. As demonstrated by Patton (2020) study, a lack of resources is a major obstacle for teachers in productively implementing STEM education.

Furthermore, effectively integrating STEM education into the school curriculum is also critical. Research by Yang et al. (2023) found that teachers who are confident in their ability to execute and design STEM education are more likely to be committed to this aspect of education. Therefore, it is important for educational institutions to provide a curriculum that facilitates the smooth integration of STEM concepts, allowing teachers to apply these approaches more easily in their daily teaching.

From a broader perspective, this understanding is crucial for helping policymakers, educators, and researchers to identify and apply strategies that can enhance teachers' commitment to STEM education. By understanding what is effective and what is not, and why some approaches are more successful, they can design appropriate and useful interventions that match the needs of teachers and the educational contexts they face.

Moreover, this understanding not only improves the quality of teaching but also the learning outcomes of students. Teachers who are more committed to implementing STEM pedagogy will provide students with opportunities to receive a more comprehensive and challenging education, preparing them well for a world increasingly focused on STEM fields. Improvements in STEM education will open up more opportunities and enhance learning outcomes for future generations, ensuring they are prepared to meet global challenges.

Success in STEM education requires not only investment in material resources but also in human development, particularly teachers, who are a crucial element in the learning process. Professional development programs, ongoing support, and a deep understanding of the needs and challenges faced by teachers are critical in the implementation of STEM education. With a more focused and comprehensive approach to supporting teachers, we can ensure that STEM education not only grows in quality but also in reach and impact on society.

IV. METHOD

Research Design and Sampling

This study employs two sampling techniques: cluster random sampling and simple random sampling, to obtain the sample size for the actual study. The total population of teachers is first identified, followed by the calculation of the sample size using the calculation suggested by Bartlett, Kotrlik, and Higgins (2001), which uses Cochran's formula (1977). An addition of 40 to 50 percent to the study sample is made to avoid loss of questionnaires during the mailing and collection process (Salkind, 2019).

This study added 40 percent to the sample size to address the insufficiency of questionnaires. Based on data obtained from the Educational Planning and Research Division (EPRD) at the Ministry of Education Malaysia (MOE), there are a total of 74 schools in Melaka, comprising National Secondary Schools (SMK), Fully Residential Schools (SBP), National Religious Secondary Schools (SMKA), and Government Aided Religious Schools (SABK) with a lower secondary STEM teacher population of 2645. The total population of STEM field teachers is 2645. A total of 100 STEM field teachers were involved in the pilot study.

Therefore, after excluding 100 respondents involved in the pilot, the number of teachers used in the sample size calculation is 2545. The sample size calculation using the method proposed by Bartlett, Kotrlik, and Higgins (2001) which employs Cochran's formula (1977) resulted in 334 teachers. The researcher added 40% to the sample size from 334 people, which is an additional 134 people to overcome the insufficiency of questionnaires.

This makes the total sample size 468 people. The procedure was carried out using cluster sampling, which allowed for the determination of the sample size for each of the four types of schools in Melaka. By estimating according to the percentage of teachers, the sample size was identified, and then simple random sampling was used. After obtaining the number of samples according to the type of school, the researcher selected these samples using the fishbowl technique. The researcher obtained the names of teachers from the schools and wrote them on slips of paper which were placed into containers for each type of school. To obtain 468 samples, the researcher conducted 421 draws from the container labelled for SMK, 14 draws for SMKA, 19 draws for SABK, and 14 draws for SBP.

Questionnaire

This questionnaire was adapted from existing instruments. The items on teacher commitment in the implementation of STEM education were adapted from Nor Azni's (2015) questionnaire instrument, which is based on the model by Herscovitch and Meyer (2001) and the instrument testing the application of the three-component model of workplace commitment (J. P. Meyer & L. Herscovitch, 2001). Meanwhile, the items on teacher readiness in STEM education were adapted based on the Self-Assessment Instrument of Teacher Competence in Science, Technology, Engineering, and Mathematics (STEM), by the MOE (2020). The items on principal competency from the teachers' perspective were prepared

based on the adaptation of the Instrument for the Status of STEM Education Implementation in Schools, by MOE (2021).

Data Collection Methods

This study required obtaining prior permission through the Educational Research Application System 2.0 (eRas 2.0) from the Educational Planning and Research Division (EPRD) of the MOE to apply for permission to conduct research in schools. Approval to conduct the study was received two weeks after the application was submitted. Permission from EPRD allowed the study to submit applications to the State Education Department (JPN). Approval from JPN was necessary to administer the questionnaire in schools. School-level permission was required before asking teachers to respond to this questionnaire. Once the principal granted permission, the researcher mailed the questionnaire and gifts to the teacher representative appointed by the principal to administer and manage the questionnaire. The researcher gave teachers a two-week period to respond and personally collected the questionnaires to save time and expedite the data collection process. However, 361 respondents provided feedback on the given questionnaire.

Data Analysis

Before the descriptive analysis step, the data must go through an initial data preparation process. This involves data entry, data screening, variable screening, checking for data outliers, and deviations. During this process, no data entry errors occur (refer to the appended table). After the initial data preparation, the data undergoes a review for data outliers. Subsequently, the questionnaire data is analysed using IBM SPSS version 27 for descriptive data analysis to address the first to third research questions: (i) What is the level of principal competency in implementing STEM education?; (ii) What is the level of teacher readiness in implementing STEM education?; and (iii) What is the level of teacher commitment in implementing STEM education?

V. FINDINGS

Descriptive analysis is used to address the first to third research questions. Descriptive statistics are employed to answer the first research question without involving hypothesis testing. Assessments are made based on the mean score (M) and standard deviation (SD) for each variable, which provides an overview of the variables studied

Research Question 1*: *The level of teacher commitment in implementing STEM education

The teacher commitment construct comprises three sub-constructs: affective commitment, continuance commitment, and normative commitment. Table 1.1 presents details of the descriptive statistical analysis findings, including the mean scores, standard deviations, and the overall level of teacher commitment in the implementation of STEM.

TABLEDESCRIPTIVE ANALYSIS AND TEACHER COMMITMENT LEVEL

Aspect		Mean (M)	Standard Deviation (SD)	Level
Construct	Teacher commitment	4.339	.436	Very high
Sub-construct	Affective commitment	4.483	.476	Very high
Sub-construct	Continuance commitment	4.263	.468	Very high
Sub-construct	Normative commitment	4.271	.497	Very high

Based on the descriptive analysis of teachers' commitment in implementing STEM education, the overall findings indicate that the level of teacher commitment is very high (M = 4.339, SD = .436). The Affective Commitment sub-construct recorded a very high level (M = 4.483, SD = .476), with each item under this sub-construct also reflecting a very high level. These results suggest that teachers possess a strong desire to support change, with confidence and belief that the transition from traditional teaching and learning (T&L) methods to STEM-oriented T&L will yield positive benefits.

The Continuance Commitment sub-construct demonstrated a very high level (M = 4.263, SD = .468), with almost all items within this sub-construct indicating a very high mean score, except for item KMB05 (‘I prioritise STEM education despite having many other important tasks to complete’), which was rated at a high level. The findings suggest that teachers comply with and accept the shift from traditional teaching and learning (T&L) to STEM-based T&L as initiated by the organisation. This acceptance is driven by the intention to avoid conflict with the school’s direction and a belief that the implementation of STEM-based T&L benefits the students.

Subsequently, the Normative Commitment sub-construct was found to be at a very high level (M = 4.271, SD = .497), with nearly all items recording a very high level, except for item KMN04 (‘I am committed to actively participating in the implementation of STEM education’) and KMN05 (‘I voluntarily implement STEM education’), which were rated at a high level. These findings indicate that teachers are committed to supporting, accepting, and implementing changes in teaching and learning (T&L) by adopting STEM-based approaches, driven by their sense of responsibility and moral obligation as educators.

Therefore, the findings of this study provide a clear depiction of the level of teacher commitment across all aspects of commitment affective, continuance, and normative towards STEM education. The results indicate that teachers are not only committed out of professional obligation but are also motivated by a strong belief in and desire for the value of STEM education. These findings are crucial for understanding how teacher commitment can serve as a foundation for supporting and effectively implementing STEM education initiatives. This also offers valuable insights for policymakers and school management in designing and executing strategies to enhance and strengthen this commitment, which in turn can influence the successful implementation of STEM education in schools.

The findings of this study can assist in evaluating and measuring the impact of teacher commitment on the

effectiveness of STEM education implementation, as well as in designing more targeted approaches to foster deeper and more sustained commitment among teachers in this field.

Research Question 2: The level of principal competency in managing and facilitating STEM education

The principal competency construct consists of three sub-constructs: principal knowledge, principal skills, and principal attributes. Table 1.2 likely details the findings from the descriptive statistical analysis, including mean scores, standard deviations, and the overall level of principal competency in the implementation of STEM.

TABLE II- DESCRIPTIVE ANALYSIS AND PRINCIPAL COMPETENCY LEVEL

Aspect		Mean (M)	Standard Deviation (SD)	Level
Construct	Principal competency	4.196	.495	High
Sub-construct	Principal knowledge	4.262	.516	Very high
Sub-construct	Principal skills	4.168	.515	High
Sub-construct	Principal attributes	4.158	.560	High

Based on the descriptive analysis of principal competency in implementing STEM education, the findings indicate that overall principal competency is at a high level (M = 4.196, SD = .495). The sub-construct of Principal Knowledge recorded a very high level (M = 4.262, SD = .516). This indicates that principals possess a very high level of knowledge in STEM education leadership and management. Nearly all items in this sub-construct also reflected a very high level, except for item KP01 (‘My principal's practices reflect knowledge of the school’s STEM goals’), which was rated at a high level.

The Principal Skills sub-construct recorded a high level (M = 4.168, SD = .515), indicating that principals possess strong skills demonstrated through best practices in STEM education. Almost all skill-related items scored at a high level, except for item KK01 (‘My principal's practices show expertise in creating a STEM environment by providing spaces for the implementation of STEM education’) and item KK08 (‘My principal's practices demonstrate proficiency in building networks and partnerships related to STEM education when the school community is involved in collaborative STEM programmes with external parties’), both of which were rated at a very high level.

The Principal Attributes sub-construct also showed a high level (M = 4.158, SD = .560). This reflects that principal possess a high level of professional values in the implementation of STEM education. Nearly all items in this sub-construct scored at a high level, except for item KA02 (‘My principal consistently collaborates with the school community in programmes that foster students’ curiosity’) which recorded a very high mean score.

Overall, the descriptive analysis of principal competency in implementing STEM education indicates that the competency level is high. The very high level of Principal Knowledge competency reflects that principal possess a deep understanding of STEM education leadership and management. In addition, the high level of Principal Skills competency demonstrates principals’ ability to implement best STEM practices in a practical manner. Meanwhile, the high level of Principal Attributes competency signifies that principal uphold strong professional values in leading the transition towards STEM-based education in schools.

Therefore, these findings offer important contributions to understanding the role of leadership in the successful implementation of STEM education in schools. The results indicate that principals, as school leaders, play a critical role in setting the direction and providing the necessary guidance for the effective execution of STEM education. The high levels of competency in knowledge, skills, and attributes demonstrate that principals are not only theoretically prepared but also practically equipped to lead and manage STEM initiatives.

These findings also reinforce the need for continuous professional development for principals, enabling them to continually improve and enhance their capacity to manage and lead STEM education efforts. Ultimately, this will contribute to an overall improvement in the quality of education within their schools. In conclusion, the results highlight the importance of competent leadership in implementing STEM education and emphasize the necessity of sustained training and professional development for principals to ensure the success and effectiveness of STEM education initiatives.

Research Question 3: The level of teacher readiness to engage in and effectively deliver STEM education.

The teacher readiness construct consists of three sub-constructs: teacher knowledge, teacher skills, and teacher attitudes. Table 1.3 details the findings from the descriptive statistical analysis, including mean scores, standard deviations, and the overall level of teacher readiness in the implementation of STEM.

TABLE III- DESCRIPTIVE ANALYSIS AND TEACHER READINESS LEVEL

Aspect		Mean (M)	Standard Deviation (SD)	Level
Construct	Teacher readiness	3.957	.398	High
Sub-construct	Teacher knowledge	4.081	.433	High
Sub-construct	Teacher skills	3.860	.455	High
Sub-construct	Teacher attitude	3.930	.447	High

Based on the descriptive analysis of teacher readiness in implementing STEM education, the overall level of teacher readiness was found to be high (M = 3.957, SD = .398). The Teacher Knowledge sub-construct also recorded a high level (M = 4.081, SD = 0.433), with all items within this sub-construct rated at a high level. These findings indicate that teachers possess a high level of knowledge encompassing theories, ideas, principles, concepts, and understanding related to STEM teaching and learning. This suggests that teachers have a strong foundational base in the theoretical and conceptual knowledge required for effective STEM education.

The Teacher Skills sub-construct indicated that teachers' skills in implementing STEM education were at a high level (M = 3.861, SD = .455). All items within this sub-construct recorded mean scores at the high level. This suggests that teachers possess strong STEM-related skills, particularly in exploring, problem-solving, designing, and producing products.

The Teacher Attitude sub-construct was also rated at a high level (M = 3.930, SD = .446), with all items scoring at the high level. These findings reflect that teacher are well-prepared to support the success of STEM education through positive attitudes, including a willingness to share knowledge, ongoing collaboration, readiness to assist, honesty, integrity, encouragement, and constructive guidance, as well as adherence to high ethical standards.

These findings are important for policymakers, educational management, and teacher training institutions in planning and implementing strategies to enhance teacher readiness in facing the growing challenges of STEM education. The results also strengthen the argument for the need for more focused and effective resources to support teachers' professional development in the STEM field.

VI. DISCUSSION

The first discussion point relates to the finding that the level of teacher commitment towards the implementation of STEM education is very high, encompassing affective commitment, continuance commitment, and normative commitment, all of which were reported at high levels. This outcome reflects that teacher possess a strong sense of dedication to actively engage in STEM education, indicating that they not only support but also accept the integration of STEM into their daily teaching and curriculum practices. This situation is highly relevant in the current educational context, where the importance of STEM continues to rise in parallel with technological advancements and the evolving demands of the job market.

According to existing literature, numerous studies have highlighted various factors that influence teacher commitment towards the implementation of STEM education. For instance, a study by Boz (2023) reported that primary school teachers often lack sufficient training, highlighting the need for more structured and in-depth professional development. This finding suggests that although there is a willingness to implement STEM, the lack of proper training and preparation may hinder teachers' ability to deliver it effectively.

Similarly, Mwesiga nad Masulu (2020) in their study conducted in Tanzania, found that while teacher commitment was generally high, it was constrained by inadequate motivation, limited training, and insufficient institutional support. This mirrors a recurring pattern in various international studies, where poor educational infrastructure and lack of school management support are often identified as key barriers to effective STEM implementation by teachers.

Furthermore, research by Samara and Kotsis (2023) revealed that psychological capital plays a crucial role in enhancing organisational commitment among university lecturers, emphasizing the importance of psychological dimensions such as self-efficacy, emotional well-being, and professional recognition in strengthening academic commitment. This suggests that reinforcing teachers' psychological capital could be a key strategy for increasing their commitment to STEM education.

Meanwhile, Patton (2020) found that teacher acceptance of change is a key factor influencing the effectiveness of STEM implementation. Teachers who are open-minded and willing to adapt are more likely to succeed in integrating STEM into their teaching. This underscores the importance of adaptive attitudes and openness to new instructional methods as critical factors in the success of STEM education.

Diego-Mantecon et al. (2021) in their study conducted in Spain, discussed the challenges of integrating mathematics into STEAM projects. They found that teachers' readiness to adopt an interdisciplinary approach was low due to a lack of resources and practical training. These findings align with those of Shume et al.(2022). who observed that among rural teachers, the lack of hands-on training often acts as a barrier to effective teaching in areas such as engineering and technology?

From a more positive perspective, Yang et al. (2023) discovered that teachers' confidence in their roles as educators significantly contributes to enhancing their commitment to STEM teaching. This factor suggests that strengthening teachers' professional identity as agents of innovation and educators in the STEM domain can serve as an additional source of motivation for deeper engagement in STEM-oriented instructional practices.

Overall, the literature supports the view that although teachers demonstrate high levels of commitment to STEM education, various structural and psychological factors influence the extent to which this commitment can be translated into effective teaching practices. The study by Aminah Jekri & Crispina Gregory K Han (2020) highlighted the importance of teaching experience and intrinsic motivation in shaping how teachers implement and adapt STEM education within their specific contexts. Their findings also indicated that teachers who are driven by an internal desire for growth and improvement in teaching quality are more likely to adopt innovative practices in their pedagogy.

In a broader context, studies by Vetriveilmany (2024) and Azizah Mohd Mohyin (2021) discussed the role of leadership in enhancing organisational commitment and supporting teachers during instructional change. These findings are consistent with the research of (James Billy & Taat, 2020), who emphasised that a supportive and conducive school culture is essential to ensure that teachers feel valued and adequately supported in their efforts.

By understanding the various factors that influence teacher commitment to STEM education, more effective strategic planning can be developed to enhance teachers' capacity and strengthen their motivation and commitment in STEM teaching. This is essential to ensure that STEM education is not merely implemented as a routine task but becomes an integral part of dynamic and responsive teaching that aligns with the current and future demands of education. The second discussion point concerns the study's finding that the level of principal competency in implementing STEM education is high, encompassing aspects of knowledge, skills, and attributes. This is a significant finding

that marks a notable shift in educational leadership capacity. The result contrasts sharply with much of the existing literature, which often reports deficiencies in these areas as contributing to ineffective management and leadership in STEM education.

Previous studies by Hatisaru et al. (2023) and Kulakoglu and Kondakci (2023) highlighted a lack of disciplinary knowledge and general leadership skills, alongside inadequate infrastructure to support the effective implementation of STEM education. In contrast, the findings of this study, indicating that principals are now better equipped with the necessary knowledge and skills to manage and lead STEM efforts,reflect substantial progress in leadership professional development.

Earlier studies by Nor Aidillina Mohd. Ramli and Marinah Awang (2020) and Harun et al. (2024) revealed that weaknesses in management capabilities directly influenced student interest and the overall administration of schools. This is further supported by research from Faizuddin et al. (2022) and Dexter Silam et al. (2020), which stressed the urgent need for professional development in communication and leadership to address existing gaps in school leadership effectiveness.

Furthermore, the enhancement of leadership skills and attributes is a critical aspect, given that deficiencies in knowledge, skills, and personal attributes are often major barriers to effective school management, as highlighted by Norliza Samad et al. (2022). The findings of this study demonstrate a significant improvement in leadership development programmes, which have supported principals in overcoming these limitations and strengthening their capacity to manage and implement STEM education programmes effectively. With this increased competency, principals are now better prepared to face the challenges associated with the implementation of STEM education.

This development opens opportunities to better understand how professional development interventions can be tailored to meet the specific needs of STEM education, not only by focusing on technical aspects but also by encompassing the development of interpersonal and effective leadership skills. As emphasised by Zatun Najahah and Muhammad Faizal (2024) strong leadership capabilities, including the ability to enhance communication and engage the broader school community, are essential elements in the success of any educational programme.

These findings further reinforce the ongoing discussion on the critical role of leadership in ensuring the effective implementation of STEM education, in line with previous literature. This study demonstrates that strengthening leadership capacity can directly enhance the quality and effectiveness of STEM education implementation. Therefore, the results provide a new perspective on how improved leadership competency can influence the success of STEM education, reaffirming that leadership capacity development should be prioritised within the educational agenda.

Overall, the findings offer strong evidence that school principals are now better prepared and more capable of addressing the challenges posed by STEM education. This represents a significant step forward, not only in advancing understanding of the requirements for effective educational leadership but also in laying the foundation for future research to identify the most impactful forms of professional development interventions. These findings present an opportunity to design and implement more effective leadership development strategies within the future education system. By ensuring that principals are equipped not only with the necessary knowledge but also with effective leadership skills and positive attributes, they will be better positioned to support and lead STEM education initiatives comprehensively and successfully.

The final discussion concerns the study's finding that teacher readiness to implement STEM education is high, encompassing knowledge, skills, and attitudes. This finding contrasts with the study by P. Wu et al. (2022) in China, which found that although teachers exhibited high emotional readiness, they still demonstrated weaknesses in the practical behaviours required for effective STEM teaching. Similarly, the study by Hang et al. (2024) in Vietnam reported that a lack of training and resources remained a major barrier to efficient STEM instruction. Even though teachers possessed strong knowledge, they were not adequately equipped with the necessary practical skills.

This study is also in line with the findings of Karunarathne (2024) in Sri Lanka, who highlighted insufficient training as a key factor limiting teachers' motivation to practise STEM education. However, the findings contradict those of Abdul Latif Ahmad et al. (2023) and Shamsuddin Muhammad and Noorashikim Noor Ibrahim (2021) who found that significant deficiencies in both skills and attitudes among teachers called for more intensive and strategically designed professional training.

These results point to an urgent need for targeted interventions aimed not only at enhancing teachers' content knowledge but also at developing their practical skills and attitudes toward STEM education. Comprehensive and continuous professional development programmes are essential to ensure that teachers are fully equipped to translate their readiness into effective instructional practices that align with the goals of STEM education.

The findings of this study offer valuable insights for aligning teacher training curricula with the actual needs in the field. Research by Shidiq and Nasrudin (2021) highlighted the lack of STEM-related courses in universities as one of the factors influencing pre-service teacher preparedness. This situation signals the need for curriculum reform and the enhancement of professional training programmes that are more effective and relevant to the current demands of the education sector.

This study also emphasises the importance of supporting teachers with better resources and sustained professional development. As noted by Suganti Ealangov and Khairul Azhar Jamaludin (2024) although there is high readiness for project-based learning, a lack of deep understanding of STEM concepts persists indicating the need for more in-depth and impactful professional development interventions. Such efforts are essential to ensure that teachers are not only prepared in principle but are also capable of delivering STEM education effectively in diverse and dynamic classroom contexts.

A comparison between previous studies and the findings of this study confirms that the challenges faced by teachers in implementing STEM education represent a global issue that requires structured and strategic solutions. Studies by P.

Wu et al. (2022) and Hang et al. (2024) show that, despite geographical differences, similar challenges persist namely, insufficient training and lack of adequate resources. It is essential to address these issues through a deeper awareness of the obstacles and the implementation of practical strategies to overcome them. This includes the development of comprehensive training programmes that not only enhance content knowledge but also cultivate practical teaching skills and foster positive attitudes towards STEM education.

The findings of this study reaffirm the importance of a holistic teacher training approach that integrates knowledge, skills, and attitudes into teacher preparation for STEM. Such an approach is critical in equipping teachers with strong theoretical foundations, practical capabilities, and the confidence needed to implement STEM education effectively. This, in turn, supports the sustained consistency of STEM implementation among teachers.

In summary, the results of this study strengthen the understanding that a comprehensive and strategic approach to teacher training is essential to ensure that educators are fully prepared to meet both current and future educational challenges. Therefore, it is imperative to implement well-structured global initiatives to address these gaps, ensuring that all teachers are provided with the necessary resources, support, and professional development to deliver STEM education effectively.

VII. CONCLUSION

Although this study found that the levels of principal competency, teacher readiness, and teacher commitment towards the implementation of STEM education are high, the level of STEM culture in schools remains low. The mismatch between the preparedness of implementers (i.e., principals and teachers) and the actual level of STEM cultural integration suggests the existence of other underlying factors that have yet to be fully explored, which may significantly influence the success of STEM implementation. Therefore, several directions for future research are proposed.

The first suggestion is to conduct research on contextual factors that may have a direct or indirect impact on the implementation and institutionalisation of STEM education. These include school climate, organisational work culture, the degree of collaboration between teachers and administrators, as well as the involvement of parents and the wider community in STEM programmes. These factors can shape an environment that either supports or hinders schools' efforts to foster a strong STEM culture. Research focusing on these dimensions may help explain why, despite the readiness and commitment of principals and teachers, STEM implementation has yet to become fully embedded in school practices.

The second recommendation is to investigate the effectiveness of policies and implementation guidelines for STEM education introduced by the Ministry of Education Malaysia. Further studies could examine the extent to which these policies are understood and internalised by schools, and how they are translated into consistent and effective practice. This could involve document analysis, interviews with school administrators, and studies on implementers' perceptions to identify gaps between policy design and actual implementation.

Future research is also encouraged to adopt qualitative approaches such as case studies or phenomenology to explore the lived experiences of principals and teachers in implementing STEM education. These approaches can help identify hidden barriers not captured by quantitative methods, such as role conflict, workload stress, time constraints, or lack of structured guidance. Through such approaches, researchers can gain deeper insights into the strategies used by implementers and the support they need to enhance successful STEM implementation in schools.

In addition, future studies may focus on evaluating the effectiveness of existing professional development programmes for principals and teachers in the context of STEM education. This is important to determine whether the training provided has a meaningful impact on improving implementers' competencies and readiness. Such evaluations can adopt a mixed-methods approach, incorporating quantitative data such as pre- and post-training assessments, along with qualitative data gathered through interviews or participants' self-reflections.

Collectively, these recommendations are expected to open avenues for more comprehensive and interdisciplinary research, particularly in understanding the real dynamics of STEM education implementation at the school level. These future studies could contribute significantly to the development of more targeted, relevant, and evidence-based intervention strategies. Indirectly, the outcomes of such research will support the formation of more effective and sustainable education policies and practices in the effort to cultivate a progressive STEM education culture across schools in Malaysia.

ACKNOWLEDGEMENT

The authors would like to extend their heartfelt appreciation to all individuals who participated in and contributed to the completion of this article. Their valuable insights, time, and support were instrumental in ensuring the quality and success of this work. The authors are also grateful for the encouragement and assistance received throughout the research and writing process, which greatly enriched the outcomes of this study.

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