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Empowering STEM education through the role of principals: a systematic literature review

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ABSTRACT

Science, technology, engineering, and mathematics (STEM) education is increasingly recognized as a critical topic in today's educational landscape. This is because contemporary education outcomes need to equip students for the demands of 21st-century jobs. In this context, the role and strategic actions of school principals emerge as critical factors in the success of implementing and empowering STEM education initiatives. The roles and strategies of principals from various aspects need to be explored. Therefore, this study aims to delve deep into the roles and strategies of principals from various contexts through research conducted from 2021 to 2024. This study analyzes past research findings through the systematic literature review (SLR) method. The research findings indicate that a total of 20 articles reveal various roles and strategies of principals. These include leadership management, professional development, fostering a STEM-focused culture, and refining assessment methods. These findings underscore the importance of active involvement in optimizing the roles and strategies of principals across various aspects. Thus, effective STEM education relies on the commitment of principals in managing various aspects, shaping a conducive culture, and facilitating teacher development. Recognizing and embracing the multifaceted roles are paramount in navigating challenges and ensuring the effectiveness of STEM programs.

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1. INTRODUCTION

In recent times, science, technology, engineering, and mathematics (STEM) education has become of interest in preparing students to face the challenges of the modern world [1]–[4]. STEM fields are needed to drive [5]–[7] and shape a wide range of skills in the community [8], [9]. Therefore, to ensure students are equipped with the necessary skills and knowledge [10]–[14]. STEM education has become a priority in education systems around the world [15]–[18]. In this context, the role of school principals emerges as a critical factor in the success of implementing and empowering STEM education initiatives [19]–[23]. Various studies conducted worldwide regarding the roles and strategies that principals need to implement to empower STEM education in order to equip students with 21st-century skills. Therefore, this study explores the roles and strategic actions of principals across various aspects through research conducted from 2021 to 2024. This study is conducted to address the following research questions: i) What is the role of principals in empowering STEM

education effectively? and ii) What effective strategies should principals implement to enhance STEM teaching and learning?

The findings of this study are expected to highlight the critical role of school principals in the successful implementation and empowerment of STEM education initiatives, emphasizing their importance in shaping the educational landscape. By exploring the roles and strategic actions of principals across various aspects, the study findings will provide valuable information to policymakers, educators, and stakeholders about effective strategies to enhance STEM education and equip students with 21st-century skills. Additionally, the study findings will reinforce the global priority given to STEM education within education systems worldwide, demonstrating its recognition as a vital component of educational policy and practice.

Overall, the findings of this study will significantly enrich the discourse surrounding STEM education, offering valuable insights to inform decision-making processes and shape the future trajectory of educational policy and practice. Through a thorough analysis of existing literature, this review seeks to enlighten educational policymakers, school administrators, and practitioners about effective methodologies in empowering STEM education under the guidance of [6], [24]–[27]. Ultimately, it is anticipated that this review will play a pivotal role in advancing efforts to enhance STEM literacy [28]–[30] and equip students with the necessary skills [31]–[34] for success in today's rapidly evolving global landscape.

2. RESEARCH METHOD

2.1. Identification

Three fundamental stages of the systematic review approach were employed to choose many pertinent papers for this investigation. The first step involves identifying keywords and looking for similar terms utilizing dictionaries, encyclopedias, thesaurus, and previous research. Search strings for the databases Scopus and Web of Science (WoS) have been created once all relevant phrases have been chosen shown as Table 1. In the initial phase of the systematic review procedure, the current research project successfully extracted 1,712 papers from the Scopus database and 35 papers from the WoS databases.

Table 1. The search strings

Scopus	Web of Science (WoS)
TITLE-ABS-KEY (("School leadership" OR "Principal" OR "Administrator" OR "Educational management") AND ("Empowerment " OR " Implementation " OR "Best practices ") AND ("STEM education" OR " STEM learning")) AND PUBYEAR > 2021 AND PUBYEAR < 2025 AND (LIMIT-TO (EXACTKEYWORD , "STEM") OR LIMIT-TO (EXACTKEYWORD , "STEM Education") OR LIMIT-TO (EXACTKEYWORD , "STEM (science, Technology, Engineering And Mathematics)") OR LIMIT-TO (EXACTKEYWORD , "Leadership") OR LIMIT-TO (EXACTKEYWORD , "STEAM Education") OR LIMIT-TO (EXACTKEYWORD , "Instructional Practices") OR LIMIT-TO (EXACTKEYWORD , "School Leadership") OR LIMIT-TO (EXACTKEYWORD , "STEAM") OR LIMIT-TO (EXACTKEYWORD , "Principals") OR LIMIT-TO (EXACTKEYWORD , "Best Practices") OR LIMIT-TO (EXACTKEYWORD , "Science , Technology , Engineering And Mathematics") OR LIMIT-TO (EXACTKEYWORD , "Science , Technology , Engineering , And Mathematics") OR LIMIT-TO (EXACTKEYWORD , "Integrated STEM")) Access Date: 20 Februari 2024	TI= KEY(("School leadership" OR "Principal" OR "Administrator" OR "Educational management") AND ("Empowerment " OR " Implementation " OR "Best practices ") AND ("STEM education" OR " STEM learning")) Access Date: 20 Februari 2024

2.2. Screening

The initial screening process should include duplicate papers with zero paper. In the second phase, 133 papers were screened using a variety of inclusion and exclusion criteria that the researchers had created; in the first phase, zero articles were excluded. The first criterion was literature, or research publications, as they are the main source of useful knowledge. It also involves excluding books, chapters, book series, reviews, and conference proceedings from the current investigation. Moreover, the review focused solely on English-language papers. Furthermore, some terms are limited to relevant article searches only. It is imperative to acknowledge that the schedule was selected with a four-year timeline (2021–2024) in mind. A total of 1,614 publications were eliminated based on criteria.

2.3. Eligibility

133 items in total have been prepared for the third level, which is called eligibility. At this point, the titles and important content of every article were carefully examined to make sure that the inclusion criteria were met and that the papers fit within the current study and its goals. Lastly, Figure 1 indicates that 20 articles are accessible for examination as shown in Table 2.

Table 2. The selection criterion is searching

Criterion	Language	Time Line	Literature Type	Subject Area
Inclusion	English	2021 – 2024	Journal (Article)	Social Science
Exclusion	Non-English	<2021	Conference, Book, Review	Beside Social Science

2.4. Data abstraction and analysis

An integrative analysis, which examined and synthesized a variety of research designs (qualitative, mixed, and quantitative), was one of the assessment techniques in this study. The aim of the competence study was to identify relevant topics and subtopics. The data collection phase was the first stage of the theme's development. Figure 1 illustrates the method by which the writers meticulously reviewed a collection of 20 publications in search of assertions or details relevant to the topics under study. The authors then evaluated the significant new findings on STEM education and leadership. The research findings and the methodologies used in each study are the subject of investigations. Following that, the author collaborated with other authors to develop topics based on the data.

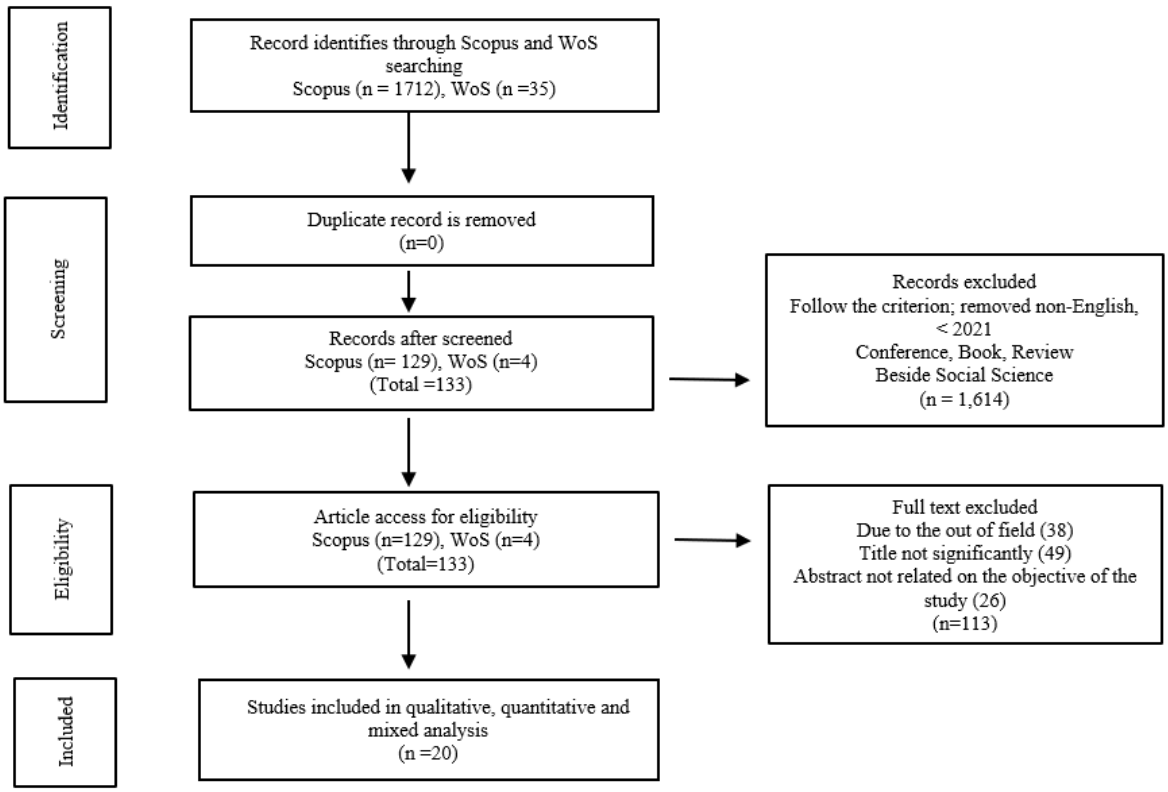

Figure 1. Flow diagram of the proposed searching study

3. RESULTS AND DISCUSSION

In this section, findings from studies conducted from 2021 to 2024 through systematic literature review (SLR) method have been summarized in Table 3. Recent research findings indicate that there are two main factors that can empower STEM education: the role of leaders and strategic leadership actions. Leaders, particularly principals, play a crucial role in shaping a school culture that supports STEM education. They need to promote a positive attitude towards STEM among staff and students. Research by Wu and Huang [35] shows that early childhood leaders have a positive attitude towards STEM and play a vital role in its implementation. Additionally, leaders need to identify key factors influencing the success of STEM education in their school context, such as institutional vision, teacher competencies, and critical resources. This requires leaders to clearly understand the needs and challenges of implementing STEM and provide necessary support and resources.

In addition to their roles, strategic leadership actions are also crucial in empowering STEM education. This includes providing appropriate professional development opportunities for STEM teachers, promoting

STEM learning programs, and creating an environment that stimulates interest and participation in STEM. Principals need to take strategic steps to address challenges and gaps in STEM implementation, as found in the study by Kulakoglu [36]. This may involve providing adequate infrastructure, recognizing a school culture that encourages STEM, and developing teachers' skills in STEM teaching. Recent research findings and in-depth discussions have been dissected to address the research question comprehensively.

Table 3. Relevant research findings

No.	Author	Research Findings
1.	Yavuz *et al.* [4]	STEM implementations increase student interest, perception, and attitudes towards STEM occupations, making STEM activities engaging and motivating.
2.	Hatisaru *et al.* [19]	Participants perceive STEM education through knowledge-code, knower-code, and élite-code perceptions, influenced by curriculum structure and reporting requirements.
3.	Rahman *et al.* [26]	Teachers' moderate knowledge of STEM education stimulates student interest, suggesting the need for further exploration of factors influencing teachers' knowledge.
4.	Wu and Huang [35]	Early childhood leaders show positive attitudes towards STEM and play a key role in its implementation, influenced by factors like institutional vision, teacher competencies, and critical resources.
5.	Kulakoglu [36]	Gaps in STEM implementation in Turkey include epistemological issues, infrastructural gaps, and mismatches with organizational culture, making it unrealistic.
6.	Murphy [37]	Leadership practices at high-performing rural schools influence STEM education success, identified through thematic analysis of interviews with principals, middle leaders, and teachers.
7.	Velasco and Milbourne [38]	STEM teacher leaders' participation in professional development programs enhances advocacy self-efficacy, crucial for sustaining STEM education.
8.	Laux [39]	Supportive leadership and teacher buy-in are essential for STEM implementation, overcoming inequities and fostering a culture of STEM teaching and learning.
9.	Natarajan and Tan [40]	STEM leadership should focus on building teachers' agency, identity, and sense of belonging to enhance the planning, enactment, and sustainability of STEM programs.
10.	Maashi *et al.* [41]	Obstacles to sustainable professional development for STEM teachers in Saudi Arabia include lack of coordination, clear plans, teacher overload, and coordination between schools, suggesting the need for collaborative teacher communities and support from curriculum stakeholders and administrators.
11.	Tuong *et al.* [42]	A study shows that Vietnamese teachers consider the application of STEM education important but face numerous challenges. The design of STEM-based lessons and student feedback on real-world problems are expected to provide further knowledge to enhance STEM teaching and mathematics education in Vietnam.
12.	Gok [43]	STEM contributes to developing 21st-century skills, but teachers report challenges with material availability from school administrators.
13.	Cabell *et al.* [44]	School counselors support underrepresented students' STEM interests, while counselor educators contribute to STEM research and training, with school administrators supporting counselors' STEM initiatives.
14.	Baker *et al.* [45]	Analysis reveals recalibration points for professional development driven by district initiatives, emphasizing connections between mathematics curriculum constraints and STEM integration.
15.	Thang [46]	Survey results highlight the advantages, challenges, and effectiveness of STEM education implementation in secondary schools, suggesting practical themes for efficient implementation.
16.	Smith *et al.* [47]	Principles for supporting PBL model of STEM education emerge from insights and focus groups, emphasizing flexible knowledge, metacognitive reasoning, collaboration, and real-world problems.
17.	Fields and Kafai [48]	These findings indicate that school administrators should support teachers better in implementing STEAM. They need to provide enough support and resources, foster a strong teacher community, and consider teachers' social and emotional needs. Administrators should also ensure that STEAM programs continue in classrooms by collaborating closely with teachers. This collaboration is crucial for ensuring smooth implementation and maximizing benefits for students.
18.	Turner *et al.* [49]	Effective strategies in interdisciplinary teaching and learning benefit teachers' confidence, knowledge, and skills in STEM program implementation.
19.	Wieselmann *et al.* [50]	District's STEM mission focuses on leadership, instructional strategies, and professional learning, prioritizing key components for providing STEM instruction.
20.	Ortiz-revilla [51]	The study emphasizes the importance of improving teachers' skills in STEM education to foster innovation. Despite the value of integrated STEM learning, teachers often lack models for effective implementation. Problem-based learning (PBL) emerges as a promising method, with four key principles identified: adaptable skills, metacognitive reasoning, collaborative motivation, and real-world relevance. These principles offer evidence-based guidance for educators considering PBL in STEM education, promoting comprehensive student development.

3.1. RQ1: What is the role of principals in empowering STEM education effectively?

Through the exploration of articles using SLR, a total of 7 articles focused on findings regarding the role of principals in empowering STEM education. The primary research findings shed light on various aspects of principal leadership in advancing STEM education, including fostering a school culture supportive of STEM education. Principals of early childhood education institutions who exhibit positive attitudes and strong beliefs towards STEM will facilitate its implementation in conducive conditions. Leaders need to be aware of

necessities such as shaping institutional vision, teacher competencies in STEM education, and critical resources, which are essential for integrating STEM into early childhood environments [35].

School leaders also need to promote a positive attitude towards STEM among staff and students. Five leadership practices contributing to the success of STEM education include leveraging community relationships, using local resources to enrich STEM learning, empowering STEM educators, promoting STEM education values, and supporting STEM pathways [37]. Additionally, leaders must consistently provide support and offer professional development programs to enhance teachers' self-efficacy in sustaining STEM education [38]. Supportive leadership, teacher support, and comfort in teaching STEM are crucial for the success of STEM initiatives. Overcoming obstacles and shifting the school culture towards STEM education require an understanding of the importance and benefits of STEM among teachers and administrators [39].

Another aspect that school leaders need to focus on is building agency, identity, and belongingness among STEM teachers to the community. These aspects are essential for meaningful planning, implementation, and sustainability of STEM programs and emphasize the critical role of teachers in educational reform [40]. Successful implementation of STEM education requires sustainable professional development for STEM teachers, including improving alignment with clear strategic plans, reducing high teaching loads to provide opportunities for STEM education implementation. School leaders need to provide continuous STEM professional development opportunities to teachers through collaborative teacher communities, supporting participation and implementation of teacher professional development programs [41]. Furthermore, students perceive STEM fields as integrated and find STEM activities engaging, motivating, and increasing their interest in STEM professions [4]. School leaders should support STEM programs and teaching because STEM activities have a positive impact on students' interest, perception, and attitudes towards STEM-related careers.

These studies provide valuable insights into the impact of principal leadership on STEM education. Principals, through their positive attitudes, strategic practices, and support for teacher development, can have a significant impact on the implementation and sustainability of STEM programs. By understanding the importance of supportive leadership, reinforcing teacher confidence, and promoting a STEM teaching and learning culture, principals can address challenges and create opportunities for students to thrive in STEM fields. These findings also underscore the need for continuous professional development and collaboration among STEM educators, facilitated by integrated efforts from curriculum stakeholders and administrators. Ultimately, leveraging the findings from these studies, principals can play a vital role in driving meaningful reform and effectively empowering STEM education in their schools and communities.

Several suggestions for further research based on the findings of conducted studies are as follows. Firstly, a longitudinal study could be conducted to track the long-term impact of principal leadership on STEM education. This could involve following schools over several years to assess how continuous leadership practices influence the outcomes of STEM programs. Secondly, comparative studies could be undertaken to compare the effectiveness of different leadership styles and strategies in promoting STEM education. This could involve examining schools with varying levels of principal involvement in STEM initiatives to determine best practices. Additionally, investigating the types of professional development programs most effective in enhancing the effectiveness of STEM teaching and learning among STEM educators could provide valuable insights. This could involve experimental studies to assess the impact of various training methods on teacher skills. Furthermore, exploring how cultural factors influence the implementation of STEM education initiatives could provide valuable insights. This could involve cross-cultural studies comparing leadership practices and STEM program outcomes in different educational contexts.

Another suggestion is to further explore students' perceptions of STEM education and its impact on their career aspirations. This could involve qualitative research to gain insights into how STEM initiatives shape students' attitudes and interests in STEM fields. Additionally, investigating the role of community engagement in supporting STEM education could provide valuable insights. This could involve case studies of schools successfully leveraging community resources to enhance their STEM programs. Finally, examining the relationship between access to infrastructure and resources and the success of STEM education initiatives could be valuable. This could involve quantitative studies to assess how factors such as technology availability and curriculum resources impact STEM program outcomes. Pursuing these research avenues can enhance our understanding of the role of principal leadership in empowering STEM education and identify strategies for improving STEM programs in schools.

3.2. RQ2: What effective strategies should principals implement to enhance STEM teaching and learning?

The search findings from 2021 to 2024 using SLR identified 13 studies focusing on principals' strategies in implementing STEM Education. There are aspects that principals need to address to strengthen STEM education, including leadership and school management, support for teachers and staff, curriculum integration, and program management and initiatives. Practical and relevant STEM education enables students to acquire critical thinking skills, work collaboratively, manage time, solve problems, and develop information-

seeking and selecting skills, such as 21st-century skills [42]. The strategic actions of principals in school leadership and management can be as crucial. This is because although teachers acknowledge that STEM contributes to the development of 21st-century skills in students, they face constraints in implementing STEM education due to school leaders failing to provide the necessary resources for STEM education implementation [43]. School leaders need to address issues related to weaknesses in STEM implementation, including conceptual, infrastructural, and organizational culture issues. Efforts to integrate STEM into education are hindered by significant deficiencies in this regard [36].

School leaders need to provide support to teachers and school staff to empower STEM education by encouraging them to engage in STEM professional development. Counselors play a crucial role in supporting students who may be less inclined towards STEM fields and ensuring equal opportunities for all students. Administrators should also authorize counselors to focus on career interventions in STEM fields [44]. School administrators need to support school counselors in seizing opportunities to enhance their skills in STEM fields. They should also consider counselors' suggestions to assist students who may be underrepresented in STEM fields and ensure all students have equal opportunities. Administrators also need to ensure that anti-racist policies are taken into account to ensure fair diversity in STEM courses. Furthermore, STEM-related documents should be available in multiple languages to ensure broader accessibility. Administrators should also authorize counselors to focus on career interventions in STEM fields.

Principals play a role in strengthening teacher professional development by promoting the use of STEM learning concepts. This includes ensuring training programs focus on these concepts, encouraging collaboration between researchers and teachers, providing ongoing support to staff, promoting a culture of continuous learning, and integrating these concepts into school policies [45]. Additionally, school leaders need to focus on supporting teachers in implementing comprehensive STEAM curricula. Teachers should prioritize building students' confidence in key areas while also developing their confidence in other important areas [26]. This underscores the need to support holistic learning and the development of student confidence in various fields through the implementation of comprehensive STEAM curricula [19].

Strategic actions by school leaders include ensuring teachers' and administrators' understanding of STEM education, adapting curriculum and lesson plans, investing in STEM facilities, enhancing teacher training in aspects such as problem-solving and instruction, and arranging training sessions that fit teachers' schedules. Emphasis should also be placed on training content that provides real benefits, possibly becoming subjects for further research [46]. School leaders need to take steps to introduce or enhance PBL approaches in STEM curricula. This involves providing adequate training and support to teachers to understand and effectively implement PBL approaches. Furthermore, school leaders need to ensure the availability of necessary resources, including infrastructure and relevant learning materials. By taking these steps, school leaders can play a crucial role in building teacher capacity and strengthening STEM education in schools [47]. School leaders need to implement strategic actions in managing programs and initiatives such as considering ways to maintain consistent STEAM programs in the classroom. This requires close collaboration between administrators and teachers to ensure smooth implementation of STEAM and maximize benefits for students [48]. Additionally, school leaders should strengthen collaboration between teachers and instructional coaches in understanding and implementing STEM teaching and learning in the classroom, including resource provision. By promoting awareness and providing adequate resources, school leaders can ensure the success of STEM integration in schools [49].

School leaders play a crucial role in transitioning to STEM education approaches. They focus on developing STEM programs, supporting teachers in STEM teaching, and ensuring smooth implementation of STEM initiatives. However, school leaders also face challenges such as resource shortages, the need for professional development, and difficulties in adapting existing curricula to STEM approaches [50]. In summary, school leaders need to take actions such as strengthening educators, developing integrated curricula, enhancing educator expertise, monitoring and evaluating intervention impacts, and promoting research and collaboration with the educational community to maximize the positive effects of STEM and STEAM interventions on student creativity development [51].

For further research, it is suggested to explore the effectiveness of implementing STEM and STEAM education at the secondary school level from both qualitative and quantitative perspectives. This entails several proposed avenues for further study, including utilizing case studies to examine the challenges and successes of integrating STEM and STEAM into school curricula, conducting longitudinal studies to assess their long-term impact on academic achievement and student skill development, comparing implementation across countries to identify best practices, investigating the influence of teacher training on student learning, and examining organizational factors within schools that affect implementation. These studies aim to provide deeper insights into enhancing STEM and STEAM education at the secondary level, ultimately benefiting student learning outcomes.

4. CONCLUSION

The implications of the discussed studies contribute significantly to the development of STEM education in Malaysia. Understanding effective leadership management in STEM schools can guide administrators in implementing successful strategies to enhance STEM education outcomes. Further research can explore best leadership practices for replication and scaling in the Malaysian context. Additionally, emphasizing continuous professional development and support for educators in STEM education can improve the quality of teaching and learning. Future studies could focus on developing tailored teacher training and leadership programs for STEM education in Malaysia. Moreover, research on cultivating STEM culture and community development can inform the development of responsive STEM education programs and policies that address cultural diversity. Continued research efforts in professional development, teacher leadership, and assessment methods can further enhance STEM education practices and outcomes in Malaysia. Overall, these findings provide valuable insights and directions for advancing STEM education in Malaysia.

The research findings illuminate various aspects of principal leadership in advancing STEM education, including fostering a school culture supportive of STEM education. The importance of principals in early childhood education institutions who exhibit positive attitudes and strong beliefs towards STEM is highlighted, as they facilitate its implementation in conducive conditions. Principals need to be cognizant of necessities such as shaping institutional vision, teacher competencies in STEM education, and critical resources essential for integrating STEM into early childhood environments. Additionally, school leaders must promote a positive attitude towards STEM among staff and students. Leadership practices contributing to the success of STEM education include leveraging community relationships, using local resources to enrich STEM learning, empowering STEM educators, promoting STEM education values, and supporting STEM pathways.

Furthermore, continuous support and professional development programs are crucial for enhancing teachers' self-efficacy in sustaining STEM education. Overcoming obstacles and shifting the school culture towards STEM education require an understanding of the importance and benefits of STEM among teachers and administrators. Another aspect that school leaders need to focus on is building agency, identity, and belongingness among STEM teachers to the community. These aspects are essential for meaningful planning, implementation, and sustainability of STEM programs and emphasize the critical role of teachers in educational reform. Sustainable professional development for STEM teachers, reduction of high teaching loads to provide opportunities for STEM education implementation, and continuous STEM professional development opportunities for teachers through collaborative communities are vital. Additionally, supporting students' perception of STEM fields as integrated and engaging can increase their interest in STEM professions. In conclusion, these findings underscore the significant role of school leaders in advancing STEM education and provide directions for further research, including assessing the long-term impact of leadership on STEM education, evaluating professional development programs, understanding cultural factors, and refining assessment methods in STEM education.

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